MIKE FLOOD

1D-2D MODELLING

User Manual

DHI Software 2003

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1 INTRODUCTION

MIKE FLOOD is a tool that integrates the one-dimensional model MIKE 11 and the two-dimensional model MIKE 21 into a single, dynamically coupled modelling system.

Using a coupled approach enables the best features of both MIKE 11 and MIKE 21 to be utilised, whilst at the same time avoiding many of the limitations of resolution and accuracy encountered when using MIKE 11 or MIKE 21 separately. Special features of MIKE FLOOD include:

- Momentum preservation through links
- Lateral links, enabling simulation of overbank flow from river channel to floodplain
- Comprehensive hydraulic structures package
- Specialist implicit structure links
- GIS integration
- Links possible along any alignment in MIKE 21 (not just horizontally or vertically)
- A graphical user interface standard (MIKE ZERO), allowing for easy data input and output as well as data preparation and analysis.
- A thorough on-line help system, user manual and technical reference documentation
- Support and continuing commitment from DHI Water and Environment

There are many advantages to using MIKE FLOOD and many model applications can be improved through its use, including:

- Floodplain applications
- Storm surge studies
- Urban drainage
- Dambreak
- Hydraulic design of structures
- Broad scale estuarine applications

1.1 General Approach to Modelling with MIKE FLOOD

Consider the two modelling systems that are integrated: MIKE 11 and MIKE 21. By combining the two the modeller can choose the best features of both and make the best model with these features. For instance, consider the following abilities and limitations of MIKE 11:

- Has comprehensive and proven structure routines ✓
- Can model very long or complicated river systems with little computational effort ✓
- Can model one dimensional channel flow accurately ✓
- Can be easily linked to rainfall and runoff programs ✓

- Can simulate high velocity / supercritical flow conditions ✓
- Is one dimensional, so two dimensional effects such as cross-channel momentum not possible ✘
- Overland flow is difficult to model if uncertain of flowpaths ✘
- Requires more conceptualisation of flow conditions and more approximations ✘
- Cannot easily simulate a coastal situation ✘

Similarly, consider MIKE 21:

- Two dimensional means more accuracy and better resolution ✓
- Two dimensional, so overland flow can be simulated more accurately (also has efficient flooding and drying facility) ✓
- Fixed grid means less flexibility with resolving features ✘
- Nested grid option means more flexibility with resolving features ✓
- Can simulate high velocity / supercritical flow conditions ✓
- Can simulate a coastal situation ✓
- Requires more computational effort ✘
- Can be difficult to model narrow channels and flow paths, particularly if diagonal to flow ✘
- MIKE 21 boundaries must be aligned with the grid (horizontal or vertical) ✘

Consider which of these features are most desirable for your application. How can you integrate MIKE 11 and MIKE 21 to best utilise the best features, while minimising the bad features? MIKE FLOOD enables this integration to be performed easily, but it is still the modeller who decides how best to design the integrated model. This manual will help you to make the decisions on how best to create a MIKE FLOOD simulation.

2 GENERAL DESCRIPTION

At present there are six different types of MIKE FLOOD linkage available:

2.1 Standard Link

This is the standard linkage in MIKE FLOOD, where one or more MIKE21 cells are linked to the end of a MIKE11 branch. This type of link is useful for connecting a detailed MIKE 21 grid into a broader MIKE 11 network, or to connect an internal structure or feature inside a MIKE 21 grid. The link is explicit – see the scientific documentation for a full description. Potential applications are shown:

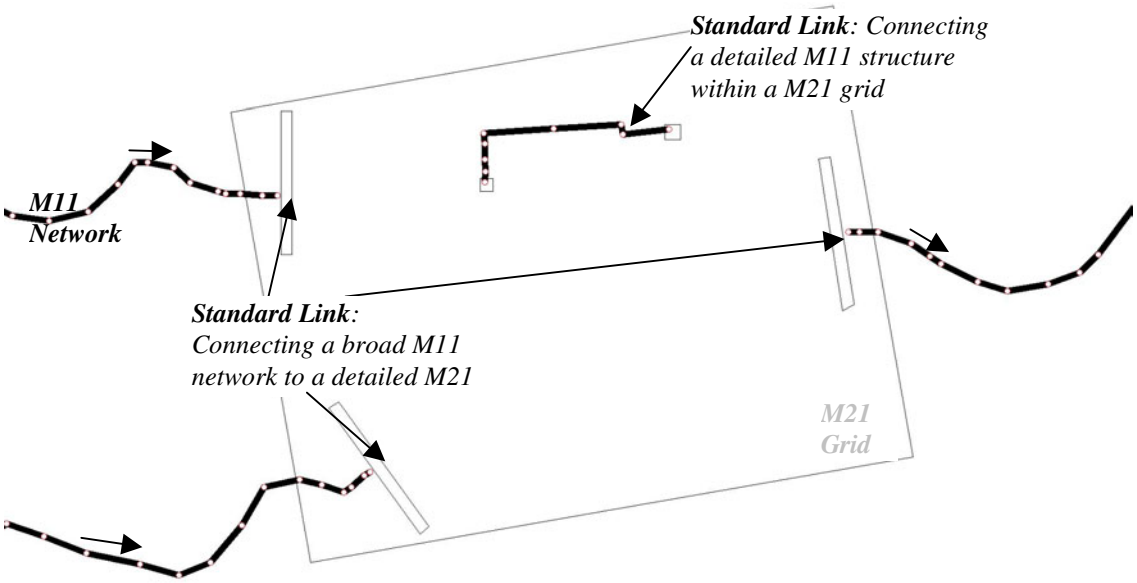

Standard Link: Connecting a detailed M11 structure within a M21 grid
M11 Network
Standard Link: Connecting a broad M11 network to a detailed M21
M21 Grid

Figure 1 Application of Standard Links

2.2 Lateral Link

A lateral link allows a string of MIKE21 cells to be laterally linked to a given reach in MIKE 11, either a section of a branch or an entire branch. Flow through the lateral link is calculated using a structure equation or a QH table. This type of link is particularly useful for simulating overflow from a river channel onto a floodplain, where flow over the river levee is calculated using a weir equation. An example is shown:

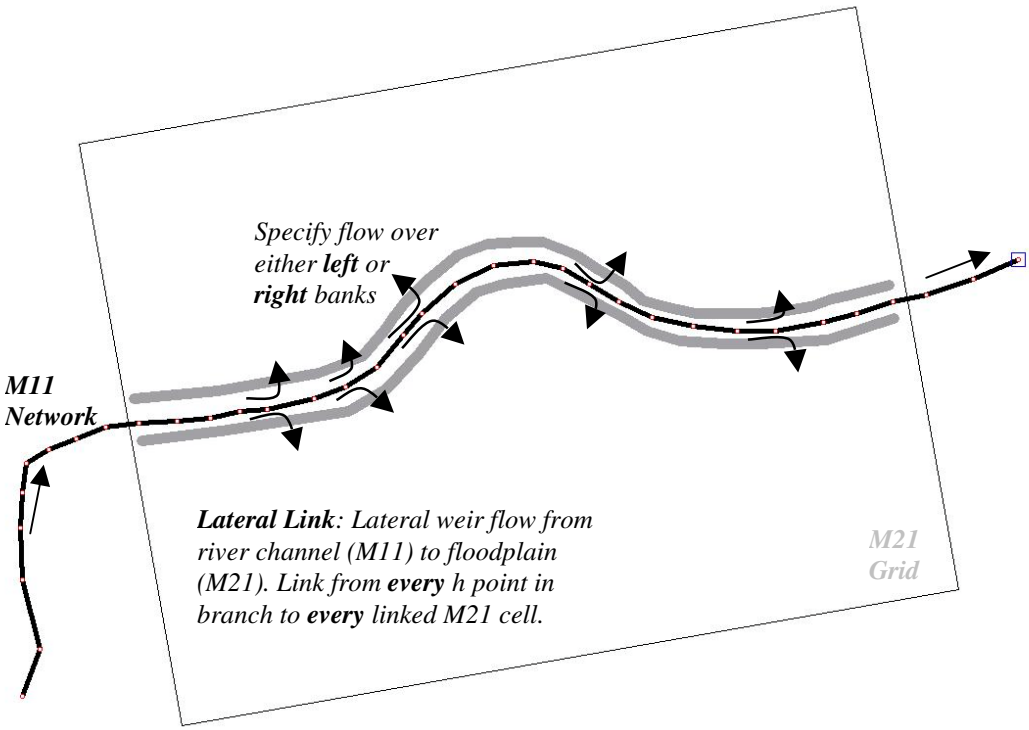

Specify flow over either left or right banks
M11 Network
Lateral Link: Lateral weir flow from river channel (M11) to floodplain (M21). Link from every h point in branch to every linked M21 cell.
M21 Grid

Figure 2 Application of Lateral Links

2.3 Structure Link (Implicit)

The structure link is the first of a series of new developments planned for MIKE FLOOD. The structure link takes the flow terms from a structure in MIKE 11 and inserts them directly into the momentum equations of MIKE 21. This is fully implicit, so should not affect timestep considerations in MIKE 21.

The structure link is useful for simulating structures within a MIKE 21 model. The link consists of a 3 point MIKE 11 branch (upstream cross-section, structure, downstream cross-section), the flow terms of which are applied to the right or top of a MIKE 21 cell or group of cells. An example is shown:

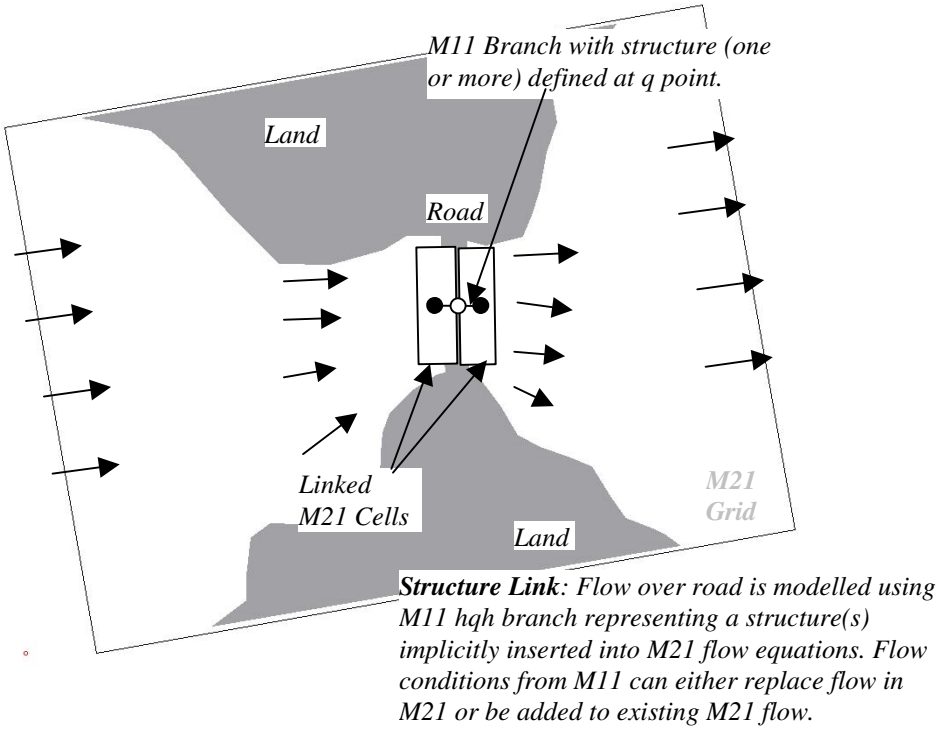

M11 Branch with structure (one or more) defined at q point.
Land
Road
Linked M21 Cells
M21 Grid
Land
Structure Link: Flow over road is modelled using M11 hqh branch representing a structure(s) implicitly inserted into M21 flow equations. Flow conditions from M11 can either replace flow in M21 or be added to existing M21 flow.

Figure 3 Application of Structure Links

2.4 Zero Flow Link (X and Y)

A MIKE 21 cell specified as a zero flow link in the x direction will have zero flow passing across the right side of the cell. Similarly, a zero flow link in the y direction will have zero flow passing across the top of the cell.

The zero flow links were developed to complement the lateral flow links. To ensure that floodplain flow in MIKE 21 does not travel directly across a river to the opposite side of the floodplain without passing through MIKE 11, zero flow links are inserted to block MIKE 21 flows. An alternative to using the zero flow links is to apply land cells which, depending upon grid resolution, may not be appropriate.

Another useful application of zero flow links is to represent narrow blockages on a floodplain, such as roads and levees. Rather than using a string of land cells, a string of zero flow cells can be used.

2.5 Standard Link (QH Extrapolation)

The standard link uses a predictor term that modifies flow from MIKE 11. This is required to establish a value in MIKE 21 that is consistent with the time centring differences in the MIKE 11 and MIKE 21 solutions. The extrapolation factor controls this predictor.

An alternative method to this is the QH extrapolation standard link. This link uses the implicit terms from MIKE 11 to produce a QH relationship through the link. In this way the predictor from MIKE 11 is in fact the slope of the QH curve.

In practice, there appears to be very little difference between the two standard link methods. It is possible that the QH extrapolation is marginally more stable, however tests show that while results using this method remain stable at higher timesteps, accuracy of the solution at these high timesteps rapidly deteriorates.

It is recommended that this link type be used with caution. It may be useful in cases where the last q point in the MIKE 11 branch is a structure (it is this situation where the extrapolation factor cannot be applied).

Finally, note that this link type requires a land cell immediately behind the link cell to maintain stability.

2.6 Going Further

The next generation of MIKE FLOOD will continue to improve and expand on the linkage and structure capabilities.

3 APPLICATION DETAILS

Any combination of links can be used in a MIKE FLOOD simulation. All the information relating to the MIKE FLOOD links is contained in one file: the ***coupling*** file (file extension .COUPLE). The MIKE11 and MIKE21 simulation files do not contain any information relating specifically to the links, except for:

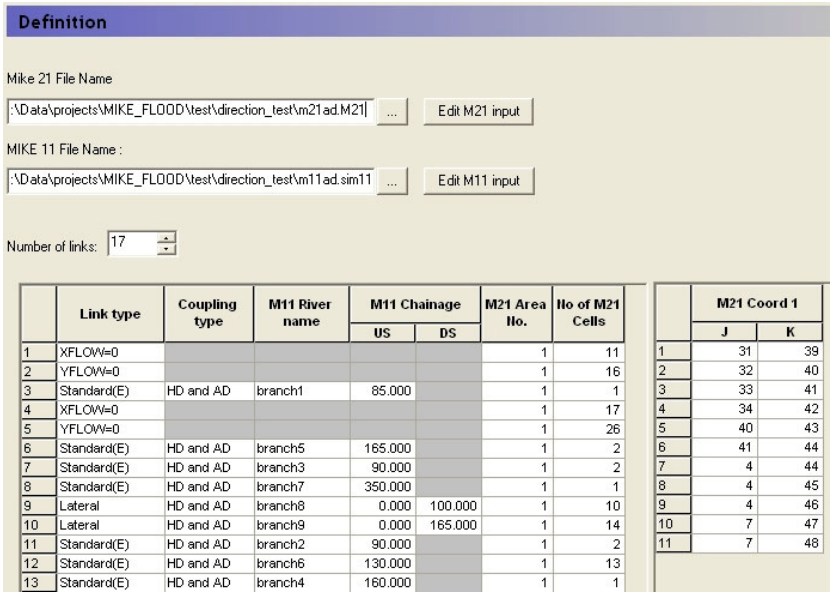
- A dummy source / sink entry must be included in the MIKE21 setup if using MIKE FLOOD;
- A dummy water level boundary condition must be applied at each link point in MIKE 11. The exceptions are lateral links and zero flow links, which do not need this.

The coupling file interface is arranged as shown:

--- MIKE FLOOD
|--- Definition
|--- Standard / Structure Link Options
|--- Lateral Link Options

The ***Definition*** menu contains information on the simulation files used in MIKE FLOOD and the general linkage definitions. Additional options for the various link types are contained in ***Standard / Structure Link Options*** and ***Lateral Link Options***.

3.1 Definition

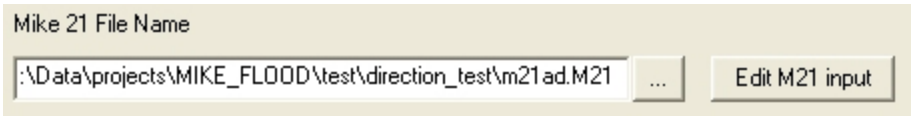


	Link type	Coupling type	M11 River name	M11 Chainage		M21 Area No.	No of M21 Cells
				US	DS		
1	XFLOW=0					1	11
2	YFLOW=0					1	16
3	Standard(E)	HD and AD	branch1	85.000		1	1
4	XFLOW=0					1	17
5	YFLOW=0					1	26
6	Standard(E)	HD and AD	branch5	165.000		1	2
7	Standard(E)	HD and AD	branch3	90.000		1	2
8	Standard(E)	HD and AD	branch7	350.000		1	1
9	Lateral	HD and AD	branch8	0.000	100.000	1	10
10	Lateral	HD and AD	branch9	0.000	165.000	1	14
11	Standard(E)	HD and AD	branch2	90.000		1	2
12	Standard(E)	HD and AD	branch6	130.000		1	13
13	Standard(E)	HD and AD	branch4	160.000		1	1

	M21 Coord 1	
	J	K
1	31	39
2	32	40
3	33	41
4	34	42
5	40	43
6	41	44
7	4	44
8	4	45
9	4	46
10	7	47
11	7	48

3.1.1 MIKE 21 File Name

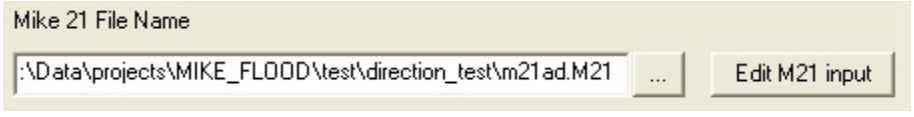
A complete MIKE 21 setup should be established and tested prior to setting up MIKE FLOOD. The MIKE 21 setup is defined in the usual way using MIKE ZERO. The path and file name of the resulting **MIKE 21 File Name** (*.m21) is provided in this menu.



A button allows for browsing the parameter file. Furthermore, the "**Edit M21 input**" button allows for opening the existing MIKE 21 parameter file for further editing.

3.1.2 MIKE 11 File Name

A complete MIKE 11 setup also should be established and tested. As with MIKE 21, this is done in the usual way using MIKE ZERO. The path and file name of the **MIKE 11 File Name** (*.sim11) is provided in this menu.



A button allows for browsing the parameter file. Furthermore, the "**Edit M11 input**" button allows for opening the existing MIKE 11 simulation file for further editing.

3.1.3 Number of Links

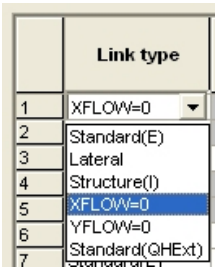
The **Number of links** can be found as follows:

- For ***standard links***, a link is the connection between the end of a MIKE 11 branch and a series of MIKE 21 cells.
- For ***lateral links***, a link is the connection between one MIKE 11 river reach (within one branch) and a series of MIKE 21 cells.
- For ***structure links***, a link is the connection between the end of a MIKE 11 branch and a series of MIKE 21 cells (same as a standard link). However, two links are required for each structure link – one for the left or bottom cell and another for the top or right cell. These "linked links" can only be one horizontal and/or vertical cell apart.
- For ***zero flow links*** (XFLOW=0 and YFLOW=0), a link is a list of cells in MIKE 21. There is no corresponding reference to the MIKE 11 simulation.

Note that the number of links is not the total number of MIKE 21 cells connected to MIKE 11 calculation points. To demonstrate, the setup shown in Figure 1 has five links, although each link contains several MIKE 21 cells. There are two links shown in Figure 2, one for the left bank lateral flow and another for the right bank lateral flow. Figure 3 has two links, one upstream of the road and the other downstream of the road.

3.1.4 Link Type

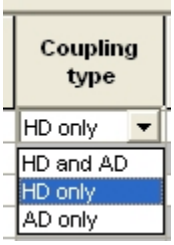
The **link type** defines the type of link:



- Standard
- Lateral
- Structure (Implicit)
- XFLOW=0
- YFLOW=0
- Standard (QH Extrap) – disabled at present

3.1.5 Coupling Type

The **coupling type** can be:



- HD only - the link will only transfer hydrodynamic information (requires HD simulation defined in MIKE 11 and MIKE 21)
- AD only - the link will only transfer advection-dispersion information (requires AD simulation defined in MIKE 11 and MIKE 21)
- HD and AD

3.1.6 MIKE 11 River Name and Chainage

- If using a ***standard*** or ***structure link***, **M11 river name** is the MIKE 11 branch with the link and **1st / US M11 chainage** is the chainage of the MIKE 11 boundary point. Note that this is not necessarily the upstream chainage in the branch (it may well be the downstream chainage) – the label "US" refers to lateral link specifications only. The same boundary

location should exist in the MIKE 11 boundary file (*.bnd11) and be defined as a *water level boundary* in the initial MIKE 11 set-up. This boundary condition specification is only to maintain consistency between MIKE FLOOD and MIKE 11 - it will be overwritten by information from the link during simulation. Furthermore, if performing an AD simulation then an *open concentration boundary* should be specified (not the Time Series dependent option).

- If using a ***lateral link***, **M11 river name** is the MIKE 11 branch with the link. **US M11 chainage** and **DS M11 chainage** define the upper and lower extents of the lateral link, so all MIKE 11 calculation points between the specified chainages will be linked to MIKE 21. Unlike the standard links, no further adjustments need to be made to the MIKE 11 boundary definitions.
- For ***zero flow links***, no MIKE 11 information is required.

M11 River name	M11 Chainage		M21 Area No.
	US	DS	
branch1	10.000		1

3.1.7 MIKE 21 Area Number

This option is available for applications with nested MIKE 21 grids. The default value (for no nested grids) is 1.

3.1.8 MIKE 21 Coordinates

There is a separate table available to enter a list of coordinates defining the MIKE 21 cells. The linked cells can be horizontal, vertical, or any other alignment. Remember that if using a ***lateral link*** the cells should be in the same sequence as increasing chainage specified in MIKE 11.

No of M21 Cells		M21 Coord 1	
		J	K
11	1	31	39
	2	32	40
	3	33	41
	4	34	42
	5	40	43
	6	41	44
	7	4	44
	8	4	45
	9	4	46
	10	7	47
	11	7	48

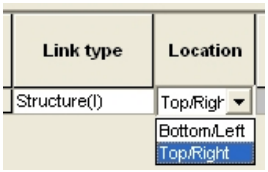
3.2 Options for Standard / Structure Links

The options listed here are only applicable for Standard and Structure links.

Standard/Structure Link Options

	Link type	Location	Mom Fact	Ext Fact	Add/Replace Mom	Depth Adjst	Activation Depth(min)	Activation Depth(max)
1	XFLOW=0						0.000	0.000
2	YFLOW=0						0.000	0.000
3	Standard(E)		1.000	1.500				
4	XFLOW=0						0.000	0.000
5	YFLOW=0						0.000	0.000
6	Standard(E)		1.000	1.500				
7	Standard(E)		1.000	1.500				
8	Standard(E)		1.000	1.500				
9	Lateral							
10	Lateral							
11	Standard(E)		1.000	1.500				
12	Standard(E)		1.000	1.500				
13	Standard(E)		1.000	1.500				
14	Structure(I)	Bottom/Left			Replace			
15	Structure(I)	Top/Right			Replace			
16	Structure(I)	Bottom/Left			Add			
17	Structure(I)	Top/Right			Add			

3.2.1 Link Type



This is carried over from the previous **Definition** menu, and cannot be edited.

3.2.2 Location

Two links are required for a ***structure link*** – one for the left or bottom cell and another for the top or right cell. These "linked links" can only be one horizontal or vertical cell apart. Define each end of the paired links with **bottom / left** or **top / right**

3.2.3 Mom Fact

Link type	Location	Mom Fact	Ext Fact
Standard(E)		1.000	1.500

This is an abbreviation for **Momentum Factor**. The **Momentum Factor** is applied to the momentum terms in MIKE21 for ***standard links***. A value of 1 means full momentum transfer through the link, while a value of 0 means that momentum transfer is not guaranteed.

Note that even if the factor is set to 0, the source term applied to the continuity equation still creates some momentum. While this is sufficient in cases where conservation is not critical (such as over weir structures or for very large MIKE 21 cell size relative to the MIKE 11 flow capacity), it will not be accurate enough for all cases. On the other hand, in some instances model stability may be improved by removing the momentum terms.

Momentum is disabled for the ***lateral links*** in MIKE 11 because of the conceptual difficulties associated with lateral flows in a 1D model.

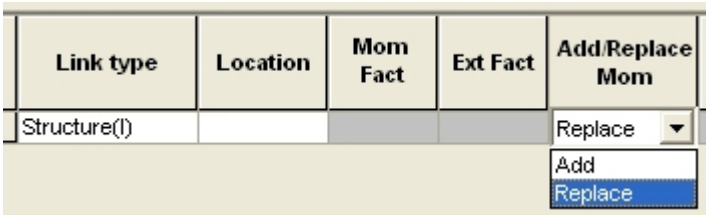
For the ***structure links***, momentum is preserved via the implicit terms and this parameter is not applicable.

3.2.4 Ext Fact

This is an abbreviation for **Extrapolation Factor**. For ***standard links***, the **extrapolation factor** has a default value of 1.5. This factor controls the time predictor in MIKE 11, which establishes MIKE 21 link values for the next timestep. If factor is set to zero, the same value at n+1 will be used as at n. **Note!** *If the last q point in the linked branch is a structure, this factor must be set to zero.*

The extrapolation factor is not applied for ***lateral links*** or for ***structure links***. For more information, see the scientific documentation (Hydrodynamics - Standard Links).

3.2.5 Add / Replace Momentum Terms



This option is available for ***structure links***.

- If the momentum terms are **replaced**, flow conditions calculated in MIKE 11 overwrite flow conditions in the MIKE 21 cell.
- If momentum terms are **added**, the flow conditions calculated in MIKE 11 are added to the flow conditions in the MIKE 21 cell.

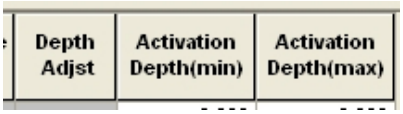
To illustrate, consider a situation where a weir structure in MIKE 11 represents a road embankment in a MIKE 21 grid (similar to that shown in Figure 3). The MIKE 11 structure flow would **replace** the MIKE 21 flow conditions.

Next, consider the same situation except with a culvert located under a section of the road. The culvert structure would be modelled in MIKE 11 (in a separate branch to the weir) and **added** to the flow conditions in the MIKE 21 cells. As long as this culvert structure link is listed in the coupling file after the weir structure link, both weir and culvert flow would be included in MIKE 21.

Consider a third possibility, where the road embankment is instead simulated as normal MIKE 21 cells. This is a reasonable practice (the upwinding facility automatically implemented in MIKE 21 has been shown to simulate weir flow well). In this situation the weir structure in MIKE 11 would not be required, and the culvert structure flows would be **added** to the MIKE 21 cells.

Note: the add / replace options mean that the order in which structure links are listed in the couple file will affect the model behaviour. By specifying "Replace" in a link, all previous link inflows from previous links will be overwritten.

3.2.6 Depth Adjustment



If depth adjustment is active, flow through a link is distributed into the MIKE 21 cells according to the water depth in those MIKE 21 cells. This is considered appropriate for links on natural terrain or channels, but may not always be applicable for structures.

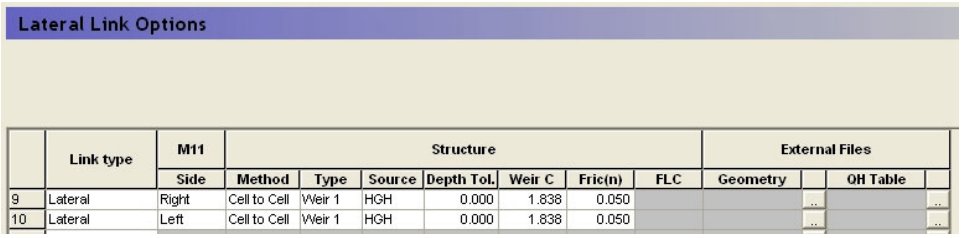
3.2.7 Activation Depth (Minimum and Maximum)

The activation depth is valid only for the ***zero flow (XFLOW=0 and YFLOW=0) links***. If specified then these links will be turned off once the activation depth is reached. A maximum and minimum value is available to gradually apply the flow conditions over a range to minimise instabilities. Note that the usefulness of this feature is uncertain.

If the minimum and maximum values are set to zero, the activation depth facility is inactive.

3.3 Options for Lateral Links

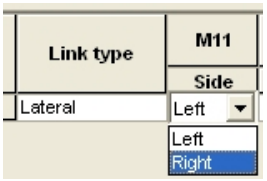
The options listed in this menu are only relevant for ***lateral links***.



3.3.1 Link Type

This is carried over from the previous **Definition** menu, and cannot be edited.

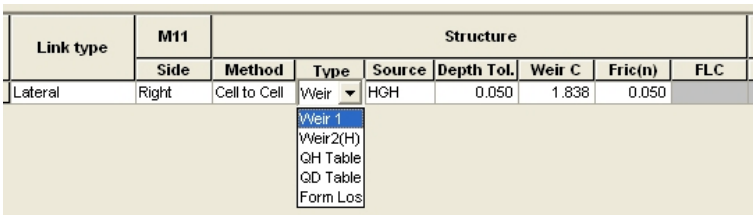
3.3.2 Side of River



Side of river defines whether the lateral link is a link on the ***left*** bank or the ***right*** bank of the river channel.

- Left bank is equivalent to Marker 1 in the MIKE 11 cross-section editor
- Right bank is equivalent to Marker 3 in the MIKE 11 cross-section editor

3.3.3 Method



The **structure method** defines the method by which flow is distributed between MIKE 11 and MIKE 21:

- The ***CELLTOCELL*** method performs a flow calculation for each individual point in the defined structure. Each calculated flow is then redistributed to MIKE 21 and MIKE 11. This means that the number of MIKE 11 points doesn't necessarily have to match the number of MIKE 21 cells.
- The ***SIMPLE*** method performs a single calculation of flow, then distributes that flow to each MIKE 21 cell and/or MIKE 11 computation (h) point.

The **CelltoCell** method is the default.

3.3.4 Structure Type

The **structure type** defines the type of flow calculation to be performed:

- ***WEIR1***: MIKE 11 Weir Formula 1 with friction term included.

- ***WEIR2H***: MIKE 11 Weir Formula 2 (Honma) with friction term included.
- ***QHTABLE***: A QH table is used, read in from an external file. Note that if using a CELLTOCELL method, the Q in the QH table is the flow per unit width.
- ***QDTABLE***: A QH table is used, except that water depth above the structure invert is used rather than water level. This could be useful if using a CELLTOCELL method with different bed levels in each cell but similar flow characteristics. This is read in from an external file.
- ***FORMLOSS***: Standard velocity head form loss equation ($\Delta h = \zeta v^2 / 2g$). The form loss coefficient can include a friction component.

The **WEIR1** type is the default. See the Scientific Documentation for more information.

3.3.5 Structure Source

The **structure source** determines where the structure geometry information comes from:

- ***M11***: Structure points are defined at each MIKE11 computation (h) point. The cross-section left or right bank markers (marker 1 or marker 3) are extracted from the cross-section database and used as the link structure bed levels. Bank levels at h points without a cross-section are interpolated.
- ***M21***: Structure points are defined at each MIKE21 cell. Bed levels from MIKE21 cells are used as the structure bed levels.
- ***HGH***: Structure points are defined at either each MIKE 11 computational h point or each MIKE 21 cell, whichever has the highest resolution. The structure bed levels are the highest of the MIKE 11 bank markers and the MIKE 21 cells.
- ***EXT***: Information is read from an external ASCII file.

The **HGH** source type is the default.

3.3.6 Depth Tolerance

In a similar way to wetting and drying in MIKE 21, a lateral link can rapidly switch between being inactive (zero flow) to active (flowing). The depth tolerance factor is used to avoid this.

3.3.7 Structure Coefficients

Coefficients controlling flow through the link structure include the **weir coefficient** (default = 1.838), the **weir exponent** coefficient (default = 1.5), the Manning's n **friction coefficient** and the **form loss coefficient**. Note that friction can be included in the weir equations – see the scientific documentation for more information.

3.3.8 External Files

If the **structure source** is EXT, an external file is specified. If the **structure type** requires a QH table to be read, a qh external file is specified. The formats of both files are shown in Table 1 and Table 2.

Table 1 Format of External Structure File

File Input Example	Description
// External file from GIS **4** **0.0 2.0** **100.0 0.0** **500.0 0.0** **1000.0 2.0**	**'//'** is a comment marker – as many comment lines as desired can be included in this file. **Line 1**: Number of entries. **Line 2 onwards**: column entries, space delimited – first column is chainage, second column is bed level.

Table 2 Format of External QH File

File Input Example	Description
// HQH file **5 3** **0.0 1.0 2.0** **0.0 0.1 0.2 0.3** **1.0 0.3 0.3 0.3** **2.0 0.4 0.5 0.7** **3.0 0.9 1.9 2.9** **5.0 10.0 20.0 50.0**	**'//'** is a comment marker – as many comment lines as desired can be included in this file. **Line 1**: Number of upstream levels (rows = nr) and number of downstream levels (columns = nc), space delimited. **Line 2**: List of nc values of downstream levels, space delimited. **Line 3 onwards (nr lines)**: List of nc+1 values of upstream level, then nc values of discharge, space delimited. **Notes**: • If QHTABLE, levels are water level • If QDTABLE, levels are water depth • If CELLTOCELL, discharge is flow per unit width • At present, upstream and downstream changes depending upon flow direction. This feature can be improved if considered useful (contact DHI for more information).

4 RUNNING MIKE FLOOD – RECOMMENDED STEPS

Errors and inconsistencies in a model setup will occur. While every effort has been made to produce clear error messages, it can be difficult to keep track of all components in the model setup. To ensure that errors are minimised, we recommend following a clear, step by step procedure to develop and run MIKE FLOOD.

4.1 Define model layout

A MIKE FLOOD model is often a compromise between model resolution (grid size) and computational time required for a simulation. Note that ***computational time is mostly influenced by the total number of wet, computational points that occur over an entire simulation***. This means that a flood simulation with a short duration, sharp peaked hydrograph will use much less computational effort compared to a long duration, flat peaked flood event. Consider this when deciding on grid resolution. Other things to consider include:

- The 1D model extent
- The 2D model extent
- Where model boundaries will be located – remember that often a MIKE FLOOD link is more flexible than applying a boundary condition directly in MIKE 21
- The alignment of the 2D grid – this may depend upon the alignment of main channels, floodplain features, etc
- The type of links to be used

4.2 Setup and Run MIKE 11 Model

MIKE FLOOD is a combination of MIKE 11 and MIKE 21. Setup MIKE 11 and MIKE 21 separately, then join them together using MIKE FLOOD.

It should be possible to completely define the MIKE 11 model that will be linked in MIKE FLOOD. This should be done to ensure that no errors exist in the MIKE 11 model. While the results of the simulation will not be correct, they may provide an indication of potential problems.

4.3 Setup and Run MIKE 21 Model

As for the MIKE 11 setup, ensure no errors exist in the MIKE 21 definition files. Run the simulation and ensure that the results are reasonable.

4.4 Setup MIKE FLOOD

The model layout should already be decided upon, and the MIKE 11 and MIKE 21 models should already have the components ready for running the MIKE FLOOD model. This step is to create the MIKE FLOOD couple file and define the links to be applied.

4.5 Run MIKE FLOOD Simulation

Note that the standard links and the lateral links are explicit (Courant conditions cannot exceed 2). It is this initial simulation where the Courant conditions are likely to be encountered, and any stability problems relating to the links will occur. Do not be surprised if several adjustments of the links need to be made at this stage, or that the timestep required is much shorter than you expected.

Check some of the tips available in this document (see Tips and Troubleshooting).

Once an initial MIKE FLOOD simulation has been completed, the modeller should have a good appreciation of the model layout and its various components, and be aware of the potential problems that may crop up in subsequent simulations and analyses.

5 PRE AND POST PROCESSING

It is envisaged that much of the pre and post processing of MIKE FLOOD will be done in a ***GIS***. The GIS provides superior tools for the management and storage of large amounts of data, which is required for many floodplain applications. However, many GIS do not have specialised tools suitable for modelling (time series analysis, grid editing, etc), so MIKE ZERO has its place in the modelling method. Also, it is likely that standard spreadsheets (EXCEL) would also be useful for data management.

Links to external programs are available at present through MIKE ZERO. Linkage properties can be imported into MIKE FLOOD either through an external ASCII file (XYZ files from a GIS) or by cutting and pasting into the MIKE FLOOD interface. Further development of useful tools for MIKE FLOOD is under way. Contact DHI for the latest progress, or check the DHI web site to download new programs.

The results from MIKE FLOOD (water levels, discharges, fluxes, AD components etc.) can be viewed using the ***Result Viewer***, ***Plot Composer*** and ***Data Viewer*** (MIKE 21) and ***MIKE VIEW*** (MIKE 11). Also, MIKE ZERO allows MIKE 21 result files to be exported to an ARC-GIS ASCII input file.

The recommended tool to use is the ***Result Viewer***, which is activated from MIKE ZERO (File-New - Result Viewer). The viewer can present 1D, 2D and 3D results from different DHI Software models at the same time, including *.res11 result files from MIKE11 and *.dfs2 results files from MIKE 21:

- New files are added to the Result Viewer project by *using Result Viewer - Projects - Add files to project* and press the new "page" icon to the right. The "*File Type*" is a scroll-down menu, where the result file is chosen.
- The work area is defined under *Result Viewer - Projects - Work Area*.
- In order to display the results together, the two models need to be based on the same geo-reference. Thus, the MIKE 11 network must be described in the same UTM metric grid as the MIKE 21 bathymetry file.
- The type of result data to display (contours and/or vectors) is selected in *Result Viewer - Projects – Active View Settings*. On-line animation as well as production of videos can be done. Time series can be extracted by using the time series button at the upper toolbar (to the right). Use double click on the left mouse button to select a point graphically and display the time series in a separate window. Use *Ctrl + Left* click to select more points graphically, and display all the time series in a separate window by use *Ctrl + Double Left* mouse click.

6 TIPS AND TROUBLESHOOTING

6.1 General Considerations

- File Layout: MIKE FLOOD Release 2003 is designed so that all information relating to MIKE FLOOD is stored in the coupling file. The MIKE 11 and MIKE 21 simulation files are standard, which means that MIKE 11 and MIKE 21 can be run separately.
- Initial Conditions: To obtain a stable MIKE FLOOD simulation, it is important that the hydraulic conditions are in dynamic equilibrium at the link point. In simplest terms, make sure that the initial water levels in MIKE 11 and MIKE 21 are the same. Alternatively, hotstart files in the MIKE 11 and the MIKE 21 setup could be used.
- Boundaries: MIKE FLOOD linkages in MIKE 21 do not necessarily need to be aligned with the MIKE 21 grid. This is different to the restrictions imposed on boundary locations in MIKE 21. Utilise this feature for any MIKE 21 simulation.
- Wetting and Drying: Any link can be initially dry, or can dry at any time in the simulation. If a link is completely dry, flow will be added to the dry MIKE 21 cells until cell water depth is above the cutoff flooding depth. Then the cell will become an active wet point.
- Timestep: The timestep in the two models can be different (MIKE 11 time step a multiple of the MIKE 21 time step), although it is recommended to use the same time step to avoid mass errors.
- MIKE 11: The DELTA coefficient dampens high frequency oscillations from a MIKE11 simulation. The frequency of the dampened oscillations depends upon the timestep and the value of DELTA. Note that the timestep for a typical MIKE FLOOD application is relatively small, which means that increasing DELTA is unlikely to have a significant effect upon the accuracy of model predictions. Therefore, increasing the DELTA parameter is therefore a very useful feature for eliminating minor wobbles and potential instabilities from a simulation. See the MIKE 11 Scientific Documentation for a more detailed description.
- MIKE 21: The default value for land in a MIKE 21 bathymetry is 10. If a floodplain model has bed elevations higher than this, ensure that the bathymetry file has this specified.
- MIKE 21: For applications with significant wetting and drying the Smagorinsky eddy viscosity formulation should **not** be used. This means that for the majority of MIKE FLOOD applications a constant eddy viscosity formulation should be applied. For overland flow conditions it is unlikely that eddy viscosity will have a major effect on model predictions (friction will dominate). However, for flow in and around structures, the value of eddy viscosity can have a significant effect upon predictions. Caution is advised in such cases.
- Additional Options: Additional options can be specified in the MIKE 21 parameter file. In the couple file, the entry **M21_Run_Info** contains four variables:
  - **Link_type** is 1 for MIKE 11 and 2 for MOUSE.
  - **Debug_type** is 0 for none and 1, 2 or 3 for debug output. If debug_type = 3 then only Courant number warnings are printed in the log file.
  - **M21_timestep_factor** is usually 1.

- **M21_ad_conversion_factor** is usually 1.0. Incoming MIKE 11 AD concentrations are divided by this value in MIKE 21.

The option **M21_struc_dirtol** applies a tolerance to linkage directions. This can be used to force flow directions in MIKE 21 to be either horizontal or vertical.

6.2 Stability

- The MIKE 11 and MIKE 21 manuals contain information on stability in numerical modelling. The comments made are equally applicable for MIKE FLOOD.
- Most issues relating to stability in MIKE FLOOD occur in the links themselves and in the wetting and drying in MIKE 21. In numerical solution of both is explicit, and the dominant constraint is the ***timestep***.
- The explicit links (Standard and Lateral) are explicit(!). The numerical design of the links however means that the local Courant conditions inside the linked cells / h points cannot exceed 2 (it is normally 1). This is important to remember – unlike a standard MIKE 11 or MIKE 21 simulation (which are semi-implicit), *if the local Courant number (C_R) is 2.00001, the model will blow up*. The local Courant number is defined as:

$$C_R = \frac{\left(v + \sqrt{gd}\right)\Delta t}{\Delta x}$$

where v = velocity, g = gravity, d = water depth, Δt = timestep and Δx = grid spacing.

- Another important factor relating to stability is wetting and drying (although there have been improvements in this area). To some extent this can be a model design issue and adjustments can be made to improve stability. For example, make troublesome link points fully wet if possible, or reduce the timestep / increase the MIKE 21 grid size (decreasing the Courant number can minimise the impact of other sources of instability). Including a depth dependence to the link, which will reduce the flow rate in shallow cells (relative to deeper cells within the link), may also help.
- See the description above in Section 6.1 (MIKE 11) pertaining to use of the DELTA coefficient in MIKE 11 to dampen potential instabilities. In most cases, increasing DELTA (to say 0.85) will not adversely affect model predictions.
- Set the momentum factor = 0.0 in links where momentum conservation is unlikely to be important.
- For lateral links, try to make the structure resolution the same as or finer than the MIKE 11 dx and the MIKE 21 grid size (the HGH structure source option is recommended).
- Lateral links can switch direction when the difference in water levels between MIKE 11 and MIKE 21 is similar. To avoid this, use the depth tolerance factor. Also, consider using a friction coefficient in the links – it is considered physically correct in situations with vegetation on the river levees, and improves link stability.
- If modelling a simple structure between adjacent MIKE 21 cells, the implicit structure link is significantly more stable than a standard link.
- Stability in a link is improved if flow is continuous in one direction only through the link (for example, cascading flow over a weir).
- Other adjustments, such as increasing friction and / or eddy viscosity, can be used to improve stability. However, such adjustments can compromise model performance.

6.3 Standard Links

- The end of branches in MIKE 11 that connect to MIKE 21 must have a water level boundary specified. This is a dummy boundary specification for initialisation purposes and will not affect the MIKE FLOOD simulation.
- Link points in MIKE21 can be dry initially, and can wet or dry during a simulation.
- A predictor (extrapolation factor) is applied for obtaining proper time centring of the values that are exchanged between MIKE 11 and MIKE 21. The predictor assumes that the flow between the last two cross-sections in MIKE 11 before the coupling is based on normal bed resistance flow (i.e. no structures). If there is a structure in the previous q-point before the coupling point, set the extrapolation factor = 0 or consider using a structure link. Note that this may affect stability of the link.
- MIKE FLOOD computes discharge from MIKE 11 and distributes it to the associated point(s) in MIKE 21. If the link in MIKE 21 consists of more points, the discharge is distributed uniformly to all points. If the depth distribution flag is used, flow is distributed according to water depth in each individual cell.
- If the time step in MIKE 11 is a multiple of the time step in MIKE 21, an interpolated discharge is transferred to MIKE 21. The discharge from MIKE 11 influences the continuity equation as well as the momentum equation. The direction of the flow is derived from comparison of the orientation of the MIKE 21 grid and the direction of the MIKE 11 branch.
- MIKE FLOOD computes the water level from the link point/area in MIKE 21 and assigns it to the associated boundary point in MIKE 11. If the MIKE 21 link consists of more points, the average value from these points is transferred to MIKE 11. In general, more than one linked MIKE 21 grid point will tend to smooth and stabilise a coupling.

6.4 Lateral Links

- When performing initial tests with MIKE 11 (with no MIKE FLOOD links), do you get the error message ***"Error no 25 : At the h-point: …. the water depth greater than 4 times max. depth."***? This can occur if the bank markers in the cross-sections (which will be laterally linked to MIKE 21) are low. To avoid this message, the **MIKE11.INI** file HD entry **WL_EXCEEDANCE_FACTOR** should be set to a higher value.
- A high resolution of MIKE 11 grid points improves model stability.
- Use the CELLTOCELL method for lateral flows.
- The WEIR1 and WEIR2H types are linked to the MIKE 11 structure routines. They include drowned conditions and simulate lateral flows accurately. The FORMLOSS method is straightforward. If these methods are not sufficiently detailed then an external QHTABLE type is available. H is considered to be water level (either at the MIKE11 h point or the MIKE21 cell). Otherwise, QDTABLE uses (water level - structure depth). Also, if a CELLTOCELL method is applied then Q is flow per unit width.
- Bed friction can be included in the weir calculation (see the Scientific Background). While this is normally uncommon for in-channel structures, riverbank overflow can often occur across reasonable distance (the levee width) and through thick vegetation. Rather than estimating a new weir coefficient to account for this, specification of a friction term may be a desirable alternative. The length of the link used in this calculation is determined from the MIKE 21 cell size.

- Lateral links can switch direction when the difference in water levels between MIKE 11 and MIKE 21 is similar. To avoid this, use the Depth Tolerance factor.
- Using the highest (HGH) structure source type is usually the most convenient method. This picks the highest resolution of points (MIKE 21 cells or MIKE 11 h points), then assigns bed levels using the highest values from the MIKE 21 cells and MIKE 11 points. If available, external input from a GIS could be used to extract more detailed bank line information.
- To view the lateral flows in the MIKE 11 results file, tick the "Lateral Links" option in the Additional Output menu of the HD Parameter File (.HD11).

6.5 Structure Links

- The structure links are implicit. This means that a simulation that uses these links will be more stable than the explicit links and simulations can be performed using longer timesteps.
- In the structure links MIKE 11 lags one timestep behind MIKE 21. Thus, the displayed value of flow in the q point of the MIKE 11 branch may not necessarily be the flow through the MIKE 21 cell. It is recommended that for structure links the MIKE 21 results be interrogated rather than the MIKE 11 results.
- A structure link entry is required for both the inlet location and the outlet location. The locations of the locations must be defined as either "Top/Right" or "Bottom/Left". The "Bottom/Left" cell is the one that will be modified in MIKE 21 – depending on the direction of the link, the x momentum (to the right of the cell) and/or the y momentum (to the top of the cell) terms will be modified.
- The MIKE 21 cells that define the inlet and outlet of the structure link must be adjacent to each other. For example, if the inlet cell is (5, 10) then the outlet cell can be (5, 11), (6, 10) or (6, 11). However, more than one MIKE 21 cell can be specified and a list of cells can be in any direction or alignment.
- The MIKE 11 branch that defines the structure link can only be a 3 point branch (one h point at the inlet, one h point at the outlet, and one q point connecting them). The q point can have as many parallel structures as are needed, or can have no structures (it can simply be a cross-section).
- There is an option to add or replace momentum terms. If the momentum terms are replaced, the flow conditions calculated in MIKE 11 overwrite flow conditions in the MIKE 21 cell. If the momentum terms are added, the flow conditions calculated in MIKE 11 are added to the flow conditions in the MIKE 21 cell.

6.6 Zero Flow Links

- A single link can be used to specify all XFLOW=0 cells in a MIKE 21 grid. The same applies for the YFLOW=0 cells. Note that at this stage the convective terms in the surrounding cells are not adjusted, which means that some inconsistencies are possible. Please contact DHI if problems occur.
- With regard to activation depth, the idea is that for most flooding conditions there will be left bank floodplain flow, in-bank channel flow and right bank floodplain flow. The interactions between these three will be governed by the MIKE FLOOD links. However, water depths could increase until the interactions between the separate flowpaths are no longer relevant. At this stage, a MIKE 21 simulation without the MIKE FLOOD links would be more accurate. By using the activation depth to switch on MIKE 21 flows across a river channel

this could be done. Note that this feature has not been thoroughly investigated, mainly because we're not sure how useful it is. Please contact DHI if you do feel this feature could be of benefit to you.

7 SCIENTIFIC BACKGROUND

The scientific backgrounds of MIKE 11 and MIKE 21 are also applicable for MIKE FLOOD.

7.1 Hydrodynamics - Standard Links

Discharge is extracted from the MIKE 11 boundary (the first Q-point), and imposed in MIKE 21 in a similar way as a MIKE 21 source discharge. The discharge is centred at timestep n+½. The discharge from MIKE 11 has an impact on the continuity equation as well as the momentum equation in MIKE 21 (as with a normal source discharge, see MIKE 21 scientific documentation).

MIKE 11 requires a water level boundary from MIKE 21 at time step n+1 in order to step from time step n to n+1. Therefore, MIKE 21 will always be one time step ahead of MIKE 11. Thus, in order to provide a discharge to MIKE 21 at time step n+½, a predictor is applied in MIKE 11 to estimate the discharge $Q^{n+½}$, given the computed discharges Q^n and water levels H^n at timestep n:

$$\frac{\partial Q^{n+½}}{\partial t} = -\left(gA\frac{\partial H^n}{\partial x} + g\frac{Q^n \cdot \left|Q^n\right|}{A \cdot C^2 \cdot R} \right)$$

where t is the time, x is the length, A is the cross-section area, C is the Chezy resistance number, and R is the hydraulic radius. The gradient in water level is at the last Q point in MIKE 11. The calculated time derivative of discharge is transferred to MIKE 21 together with the discharge at time n in order to predict the discharge at a later time step (n+½).

The predictor assumes that the convective acceleration terms in the last grid point in MIKE 11 are negligible. Furthermore, it assumes that "normal" bed resistance represented by a Chezy (or Manning number) controls the flow. Thus, a structure in the last Q grid point in MIKE 11 before a link to MIKE 21 should either be avoided or the predictor removed (see ***Extrapolation Factor*** Ext Fact). Alternatively, remove the predictor, and an extra cross-section between a structure and a link to MIKE 21, or try the structure link.

7.2 Hydrodynamics - Lateral Links

For lateral links, flow from MIKE 11 is via a lateral boundary, which is then applied into MIKE 21 via a source (and vice versa). The lateral link varies from the standard source / sinks in the following ways:

1. Flow through the link is dependent upon a structure equation and water levels in MIKE 11 and MIKE 21.
2. Flow through the link is distributed into several MIKE 11 h points and several MIKE 21 cells.
3. The lateral links do not guarantee momentum conservation.

A structure is required to calculate the flow between MIKE 11 and MIKE 21. This structure is typically a weir that represents overtopping of a riverbank or levee. The geometry of the structure can be determined from MIKE 11 bank markers, MIKE 21 cell bed levels, a combination of the highest of each, or from an external file.

With a CELLTOCELL method, the structure geometry is subdivided into a series of internal structures. Each internal structure has a bed level and a width determined from the resolution of points defined along the structure. Consider the schematic diagram below of a structure defined from MIKE 11 h points:

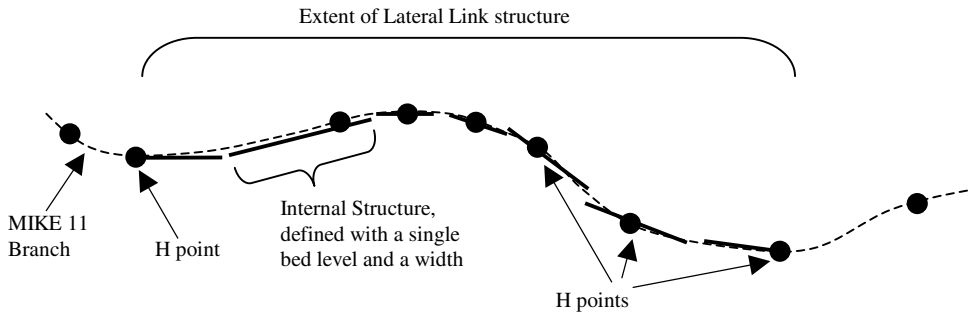


Figure 4 Lateral Link, Definition of Internal Structures

The internal structures are defined so that all of the information available in the structure geometry is utilised.

During computation, each internal structure is assigned a water level from MIKE 11 and from MIKE 21. These values are found by interpolating levels at existing calculation points onto the internal structures. Consider the schematic diagram below (Figure 5) of an externally defined structure, where the internal structure locations differ from the MIKE 21 cell locations and the MIKE 11 h point locations. As shown, water levels are interpolated from the MIKE 21 cells and the MIKE 11 h points to the specific internal structure locations.

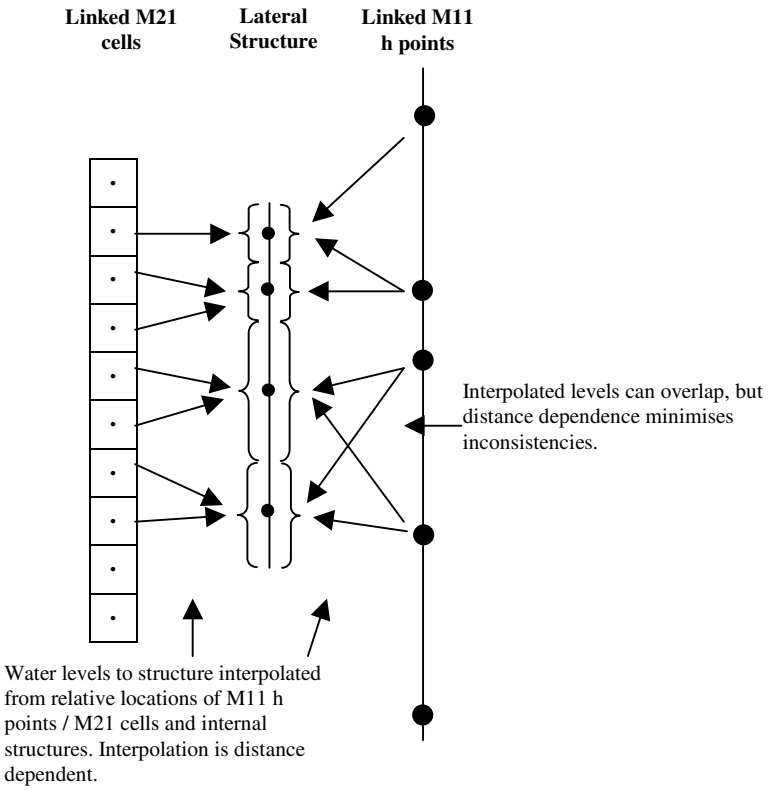

Linked M21 cells
Lateral Structure
Linked M11 h points
Interpolated levels can overlap, but distance dependence minimises inconsistencies.
Water levels to structure interpolated from relative locations of M11 h points / M21 cells and internal structures. Interpolation is distance dependent.

Figure 5 Lateral Link, Interpolation of Water Levels

Using the calculated width and bed level and interpolated water levels, the flow across each internal structure is calculated using a standard structure equation. These structure equations (weir type 1 or 2) are the same equations used in MIKE 11. The flow from each internal structure is then distributed to / from the MIKE 11 h points and MIKE 21 cells. This is done by determining the range of influence that each internal structure has upon each linked MIKE 11 h point and MIKE 21 cell. As shown in Figure 6, if MIKE 11 h points lie within the range of influence of a given internal structure, flow is distributed across those points according to water depths in each point. If no MIKE 11 h points lie within the range of influence, flow is distributed to the nearest upstream and downstream points using a distance dependent interpolation. The same applies for MIKE 21 cells.

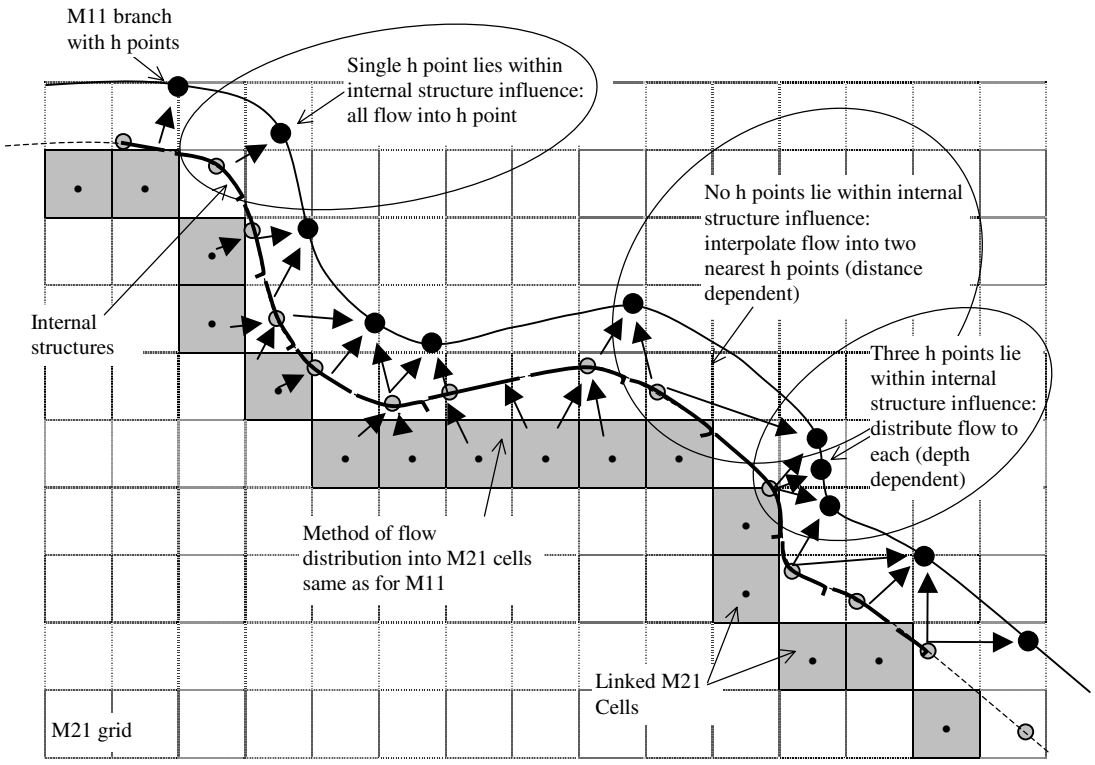


Figure 6 Lateral Link, Interpolation of Flows

This approach allows a high level of flexibility when designing the lateral link. However, it is likely that a similar distribution of MIKE 11 h points, MIKE 21 cells and internal structures will produce the most accurate solution.

7.3 Hydrodynamics – Structure Links

The structure link takes the implicit terms describing momentum through a 3 point MIKE 11 branch and uses them to replace or modify the implicit terms describing momentum across the face of a MIKE 21 cell. In this way, the flow properties from one MIKE 21 cell to another are modified to represent a structure. Consider the following diagram:

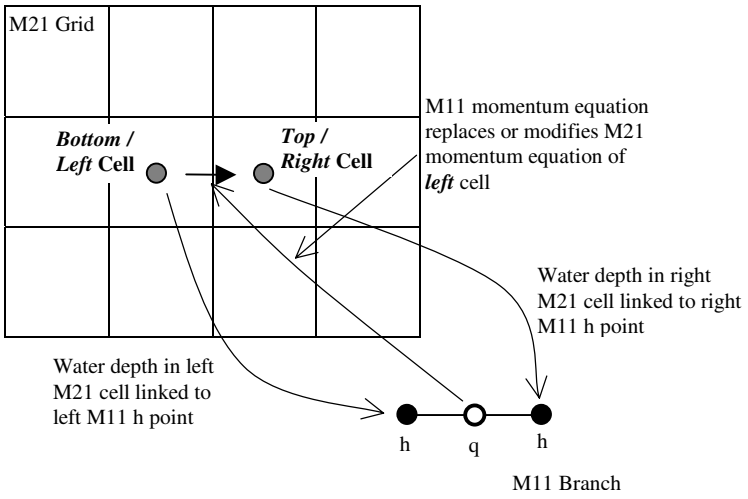

M21 Grid
Bottom / Left Cell
Top / Right Cell
M11 momentum equation replaces or modifies M21 momentum equation of left cell
Water depth in right M21 cell linked to right M11 h point
Water depth in left M21 cell linked to left M11 h point
h
q
h
M11 Branch

Figure 7 Structure Link Diagram

As shown, the momentum equation from the MIKE 11 q point replaces the x-momentum equation of the left MIKE 21 cell. This is the only thing that is modified within MIKE 21. Note that the link is directional, so the following situation can occur:

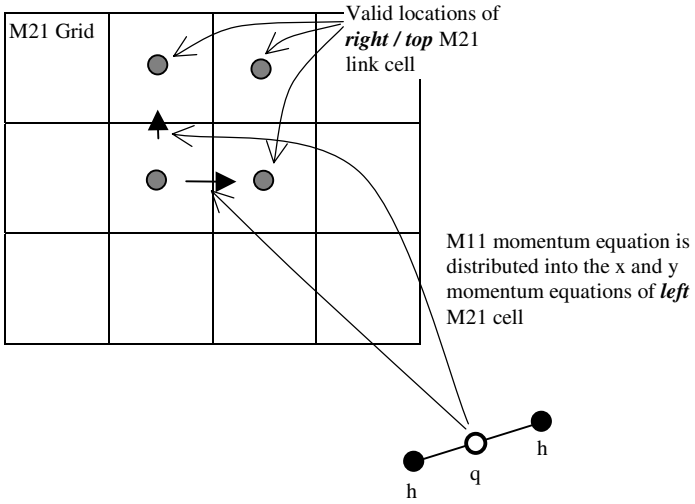

M21 Grid
Valid locations of right / top M21 link cell
M11 momentum equation is distributed into the x and y momentum equations of left M21 cell
h
q
h

Figure 8 Structure Link, Directional Link

This second case raises the question of where the right side of the link should be located in MIKE 21. The main requirement is that ***the left (or bottom) MIKE 21 cell of the structure link must be adjacent to the right (or top) MIKE 21 cell***. Therefore***, valid locations are directly to the right, directly above, or one diagonal cell to the top right***. For example, if the start of the structure link is at coordinates (10, 12), valid locations for end of the link are (11, 12), (10, 13) and (11, 13). Choice of this location will depend upon which cell is considered to be best representative of the water level at that particular structure.

If the MIKE 11 momentum equation ***replaces*** the MIKE 21 momentum equation, the implicit terms for the momentum equation within the MIKE 21 cell are replaced. Adjustments need to be made for link direction (θ) and conversion from discharge (Q) to flux (q = Q/Δ, Δ = grid spacing). For the momentum equation in the x direction:

- $a_{M21}h_{j+1}^{n+1} + b_{M21}q_{j+1}^{n+1} + c_{M21}h_{j-1}^{n+1} = d_{M21}$
- $a_{M21} = \frac{a_{M11}\cos\theta}{\Delta}$
- $b_{M21} = b_{M11}$
- $c_{M21} = \frac{c_{M11}\cos\theta}{\Delta}$
- $d_{M21} = \frac{d_{M11}\cos\theta}{\Delta}$

If the terms are ***added*** (for example if the structure link represents a structure flowing under the existing MIKE 21 topography), further adjustments are made to ensure consistency between the MIKE 11 and MIKE 21 terms. Again for the x direction:

- $a_{M21}h_{j+1}^{n+1} + b_{M21}q_{j+1}^{n+1} + c_{M21}h_{j-1}^{n+1} = d_{M21}$
- $a_{M21}^{*} = a_{M21} + \frac{a_{M11}b_{M21}\cos\theta}{b_{M11}\Delta}$
- $b_{M21} = b_{M11}$
- $c_{M21}^{*} = c_{M21} + \frac{c_{M11}b_{M21}\cos\theta}{b_{M11}\Delta}$
- $d_{M21}^{*} = d_{M21} + \frac{d_{M11}b_{M21}\cos\theta}{b_{M11}\Delta}$

The same adjustments apply for the y direction momentum equation, except a sine direction adjustment is made rather than a cosine adjustment.

Note that the implicit terms from MIKE 11 used are from the MIKE 11 solution at the previous timestep. In most applications, where flow conditions vary quite slowly relative to the timestep, this is not a problem. It may become a problem if rapid (and relevant) changes do occur over a timestep. Also, the displayed value of flow in the q point of the MIKE 11 branch may not

necessarily be the flow through the MIKE 21 cell. It is recommended that the MIKE 21 results are interrogated in this case rather than the MIKE 11 results.

7.4 Hydrodynamics – Zero Flow Links

If the link type is a XFLOW = 0 link, the x direction momentum across the right face of the MIKE 21 cell is set so that q = 0. This is done by modifying the implicit terms:

- $a_{M21}h_{j+1}^{n+1} + b_{M21}q_{j+1}^{n+1} + c_{M21}h_{j-1}^{n+1} = d_{M21}$
- $a_{M21} = c_{M21} = d_{M21} = 0$
- $b_{M21} = 1$

Similarly, if a YFLOW = 0 link, the y direction momentum across the top face of the MIKE 21 cell is set to q = 0.

7.5 Advection-Dispersion

Concentrations of AD components are transferred explicitly between MIKE 11 and MIKE 21 depending on the direction of the flow. For ***standard links*** with flow from MIKE 11 to MIKE 21, the concentration of the AD-component is imposed as with a standard MIKE 21 source, i.e. as a flux of mass into the MIKE 21points:

$$\Delta\left(\frac{\partial V \cdot C_{M21}^{n+½}}{\partial t}\right) = Q^{n+½} \cdot C_{M11}^{n}$$

When flow is going from MIKE 21 to MIKE 11, the modification to the AD-equation in MIKE 21 is:

$$\Delta\left(\frac{\partial V \cdot C_{M21}^{n+½}}{\partial t}\right) = Q^{n+½} \cdot C_{M21}^{n}$$

The corresponding boundary condition in MIKE 11 can be either a transport boundary or a concentration boundary as usual. Furthermore, a mixing coefficient can be defined as normal.

For ***lateral links***, the mass of the AD component being transferred is calculated from the lateral discharge and the concentration in MIKE 11 or MIKE 21 (depending upon flow direction). This is then applied as a source or sink term in the branches and cells. The source term into MIKE 21 is as for the standard links. For MIKE 11, the one dimensional advection dispersion equation is:

$$\frac{\partial AC}{\partial t} + \frac{\partial QC}{\partial x} - \frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x}\right) = -AKC + C_2 q$$

where C is concentration, D dispersion coefficient, A cross-sectional area, K linear decay, C_2 the source/sink concentration and q lateral inflow.

For ***zero flow links***, no advection will occur across the link due to the zero flow specification, and dispersion is turned off.

7.6 Flow Distribution by Depth

Flow is distributed according to the Chezy equation for resistance:

$$Q = AC\sqrt{RS}$$

where:

Q = Flow;

A = Area (= width * depth = w*h);

C = Chezy coefficient;

R = Hydraulic radius (approx. = depth h); and

S = slope.

Rearranging this equation gives:

$$Q = whCh^{0.5}S^{0.5} = h^{1.5}wCS^{0.5}$$

Thus, proportionality can be derived between flow and water depth (h):

$$Q \approx h^{1.5}$$

Flow is then distributed across a number (n) of MIKE 21 cells. For each cell (count i = 1 .. n), the distributed flow Q_i is calculated from the total flow Q_{TOT}:

$$Q_i = Q_{TOT}\frac{h_i^{1.5}}{\sum_{i=1}^{n} h_i^{1.5}}$$

7.7 Inclusion of Friction Term in Weir Formulae 1 and 2 (Honma)

The equation for the Weir Formula 1 is:

$$Q = wCh_1^k \left[1 - \left(\frac{h_2}{h_1} \right)^k \right]^{0.385}$$

where w = width, C = weir coefficient (1.838), k = exponential coefficient (1.5), h_1 = depth of water above weir level upstream (H_{us} - H_w) and h_2 = depth of water above weir level downstream (H_{ds} - H_w). This equation is actually a free overflow term (wCh^k) combined with a scaling term for submergence ($[..]^{0.385}$) that approaches 0 as h_1 approaches h_2. The equation for the Weir Formula 2 (Honma) is:

$$\frac{h_2}{h_1} \le 2/3 : \qquad Q = wCh_1\sqrt{h_1}$$

$$\frac{h_2}{h_1} > 2/3 : \qquad Q = w\left(\frac{3}{2}\sqrt{3}C\right)h_2\sqrt{h_1 - h_2}$$

The first equation is free overflow (identical to Formula 1 with free overflow), while the second is for submerged conditions.

Both equations are derived from the equation for form loss across a structure, where

$$\Delta h = \zeta \frac{v^2}{2g}$$

If a friction loss is added this becomes:

$$\Delta h = (\zeta + F)\frac{v^2}{2g}$$

where:

$$F = \zeta_f \frac{2gLn^2}{h_1^{4/3}};$$

ζ_f = Friction coefficient;

L = length of structure; and

n = Manning's number.

Expanding:

$$Q = w\sqrt{\frac{2g}{(\zeta + F)}}h_1\sqrt{\Delta h}$$

This equation is similar in form to Weir Formulae 1 and 2 for free overflow, except that the weir coefficient is replaced:

$$C = \sqrt{\frac{2g}{\zeta + F}}$$

Assuming that the entrance / exit losses ζ are the same, a new weir coefficient C_f can be derived from the original coefficient C and the additional friction:

$$C = \sqrt{\frac{2g}{\zeta}} \; ; \; \zeta = \frac{2g}{C^2}$$

$$C_f = \sqrt{\frac{2g}{\zeta + F}} = \sqrt{\frac{2g}{2g/C^2 + F}}$$

So, the existing equations for weir flow calculations can be used, except that the weir coefficient is modified according to:

$$C_f = \sqrt{\frac{2g}{2g/C^2 + \zeta_f \frac{2gLn^2}{h_1^{4/3}}}}$$

This equation is applied to the weir calculations in the lateral link specifications.

8 EXAMPLES

The examples presented below are designed to test the operation of the new features of MIKE FLOOD and to demonstrate the use of these features. Most are available with the DHI software release version 2003 in the "Examples" folder. Otherwise, check www.dhisoftware.com, where the input files can be downloaded.

Various MIKE ZERO tools can be used to view the results, including the Result Viewer, MIKE VIEW (not in MIKE ZERO), Plot Composer, and the time series, profile series and grid series editors.

A brief outline of the examples is provided:

- Standing wave: examines momentum transfer through standard links
- Lateral link test 1: investigates lateral link flow over a bank of varying bed levels and includes an AD component
- Lateral link test 2: investigates lateral link flow and compares results to a standard MIKE 11 weir
- Flow direction test: examines flow directions through various links
- Implicit structure link: examines the structure link and compares performance to the standard link and MIKE 11
- Floodplain flow: examines the transition from in-bank to floodplain flow in a simplified setup
- Floodplain demonstration: demonstration of a real floodplain application

Note: The MIKE FLOOD interface uses a full file path specification (including folder location / directory) for the linked MIKE 11 and MIKE 21 files. If a problem occurs when running the examples, check that the MIKE 11 and MIKE 21 files name boxes in the Definition menu have the correct file path for your system setup.

8.1 Standing Wave

Consider an 8 km long basin closed at both ends:

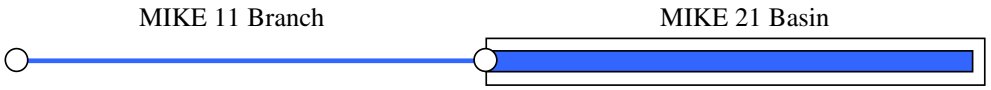


Figure 9 Standing Wave Test Layout

The width of the basin is 100 m and the mean water depth is 2.0 m. The bed resistance is C = 50 $m^{1/2}/s$. An initial disturbance of the water surface is imposed corresponding to a sinusoidal variation of range 0.10 m.

The basin is described using MIKE FLOOD. 4 km is described in MIKE 11, and 4 km is described in MIKE 21. In both models, the longitudinal grid spacing is 100 m. MIKE FLOOD simulates the transfer of mass as well as momentum between the 1D MIKE 11 model and the 2D MIKE 21 model. The water level at different times after start of the simulation is depicted below.

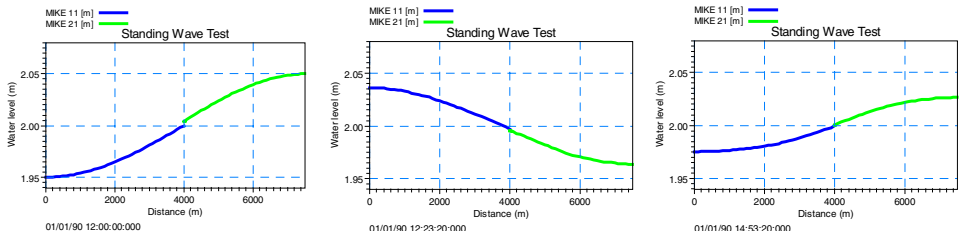


Figure 10 Standing Wave Test Results – Water Level Profiles

The files required to setup and run this example are available. These files take this example further than presented here, with tests using:

- the standard link type;
- the QH Extrapolation link type;
- a 10 cell / 1000 m wide setup of the same test case;
- a MIKE 11 model of the entire test (no MIKE FLOOD link); and
- a MIKE 21 model of the entire test (no MIKE FLOOD link).

The setup ("StandingWavew.couple") is as shown:

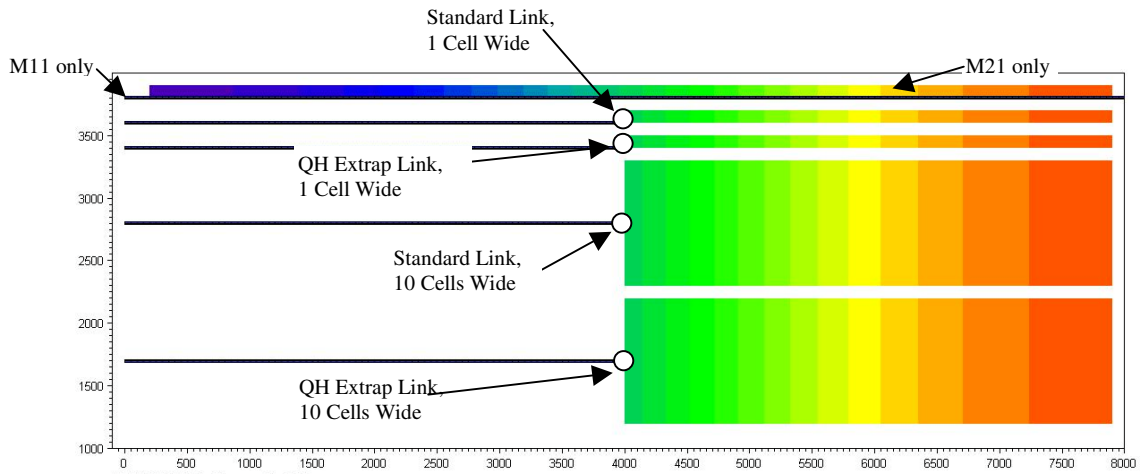


Figure 11 Standing Wave Test Layout (2)

Thus, size separate tests are included in this single MIKE FLOOD setup. The results are shown as water level profiles at various timesteps:

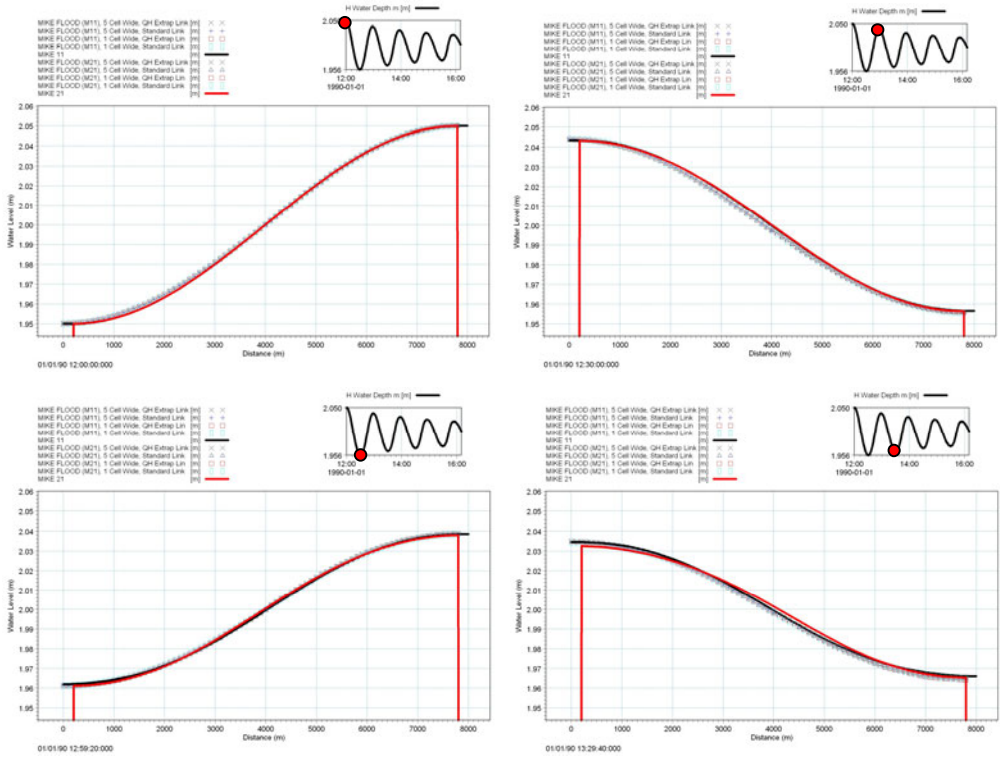


Figure 12 Standing Wave Test Results – Water Level Profiles (2)

While it is difficult to examine the individual curves, the plots shown above demonstrate that the various link types are performing satisfactorily. See the examples provided for further interrogation.

8.2 Lateral Link 1

This is a test to assess the performance of the lateral links and to illustrate their implementation. The test represents an inflow channel with overtopping onto a broad flat basin (or floodplain), as shown:

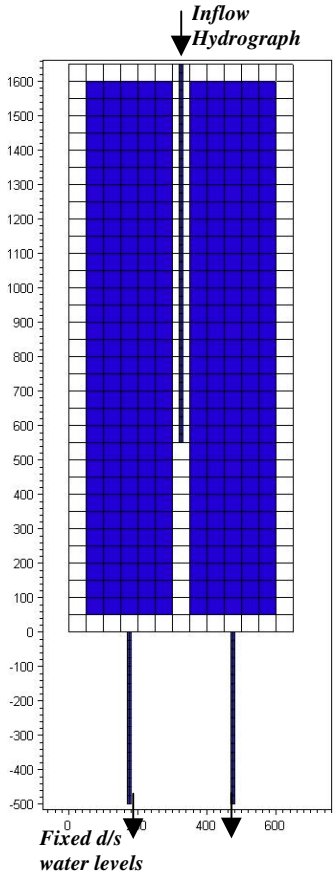


Figure 13 Lateral Link Test 1 Layout

An inflow hydrograph discharges into the upstream MIKE 11 river branch. Flow spills over the banks of the river channel and into the MIKE 21 basins. The left and right basins are separated by land. Two downstream MIKE 11 branches are connected to the end of the left and right basins. Water level boundary conditions are applied to the downstream branches. A closed boundary is applied to the downstream end of the upstream river branch.

The MIKE 11 network uses a 50 m spacing between h points, and the MIKE 21 grid has a spacing of 50 m. A simulation timestep of 15 s is used.

The links at the downstream end of the MIKE 21 basin are standard links. The main interest in this test however is the lateral links. The left bank of the upstream branch (chainage 100 m to 1100 m) is connected to the MIKE 21 cells in the right basin (7, 31 to 7, 11). The right bank is connected to the left basin (5, 31 to 5, 11).

The left and right bank markers of the branch are defined by a sinusoidal curve as shown:

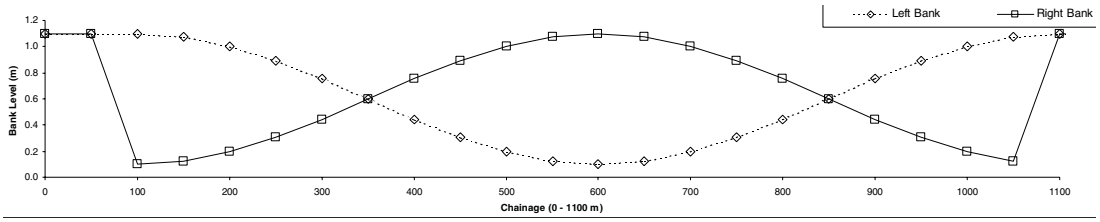


Figure 14 Lateral Link Test 1, Left and Right Bank Levels

Lateral flow spilling out of the river channel into the basin will be distributed across the length of the branch, depending upon the bank levels, the water level profile along the branch, and the flow distribution will vary between the left and right sides of the river.

The MIKE FLOOD couple file is “mf.couple”. Run this simulation, then inspect results using the Result Viewer in MIKE ZERO. Contours of water depth and vectors of velocity at two instances in the simulation are shown below:

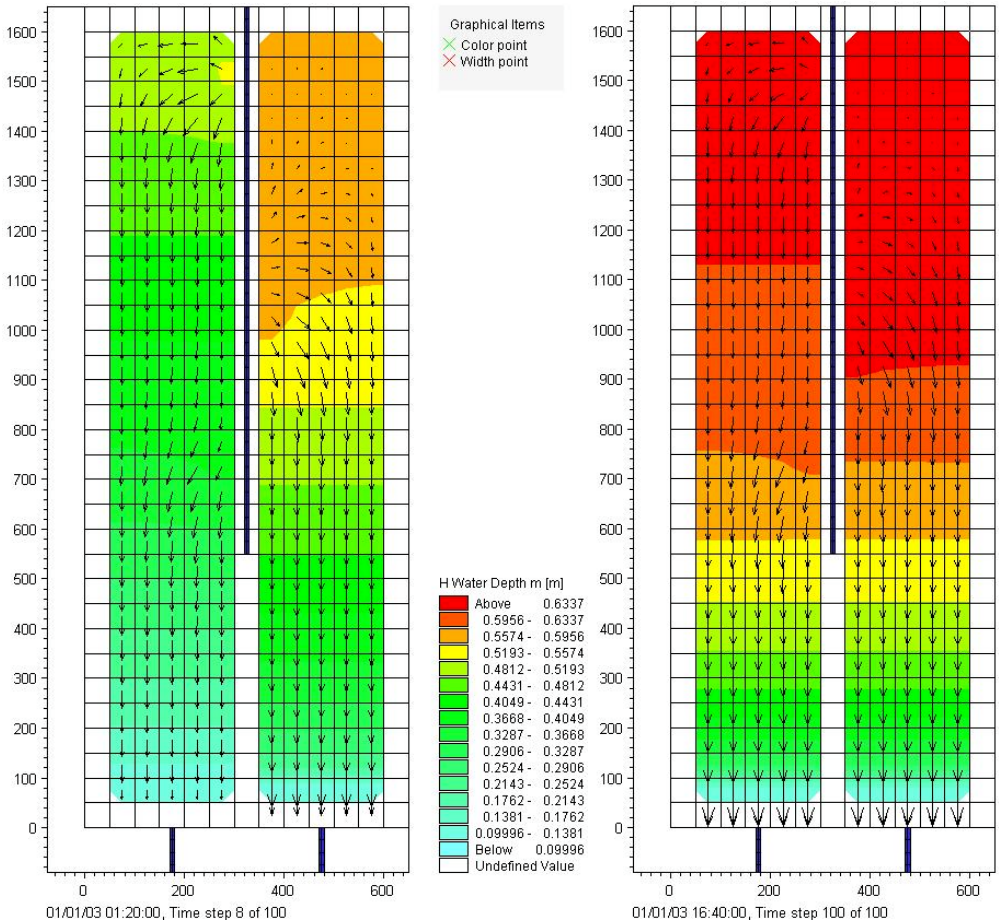


Figure 15 Lateral Link Test 1 Results –Water Depth and Velocity

There is a distinct difference in flow patterns between the left and right basins. Using MIKE VIEW, look at the longitudinal profile of the upstream branch:

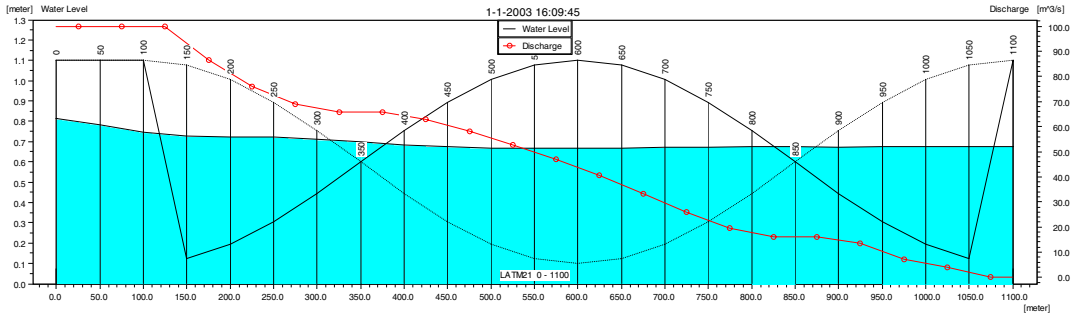


Figure 16 Lateral Link Test 1 Results –Water Level and Flow Profile

Similarly, the lateral discharges can also be presented (tick the "Lateral Inflows" button in the Additional Output Menu in HD Parameters):

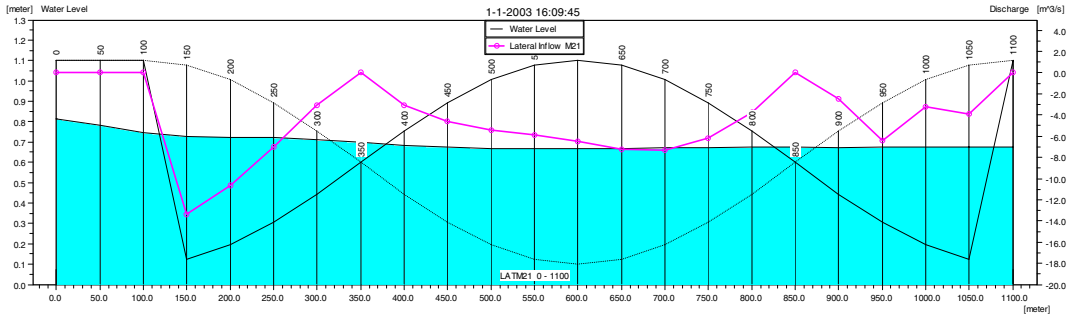


Figure 17 Lateral Link Test 1 Results – Lateral Flow Profile

Last (but not least), a check of the mass in the system can be made by comparing the total discharge into the model (the upstream inflow from the upstream branch) with the discharge out of the model (from the downstream branches):

As shown, 100 m^3/s enters from upstream. Approximately 50 m^3/s (49.96 m^3/s through the left branch and 50.04 m^3/s through the right) flows out of each downstream branch.

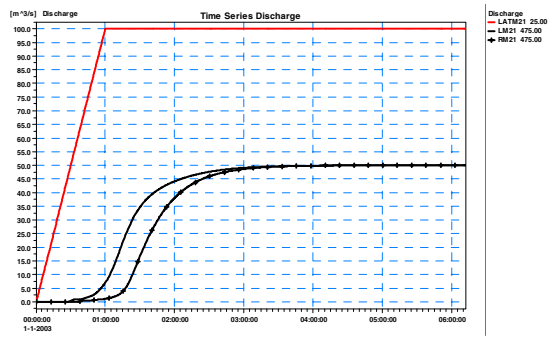


Figure 18 Lateral Link Test 1 Results –Time Series of Discharge

For comparison, the same setup has been done using MIKE 11. For the MIKE 11 setup, the left and right basins are represented using branches. Flow from the upstream branch to the basins occurs through two additional branches with cross-sections representing the bank levels. The MIKE 11 test has been combined with the original MIKE FLOOD application (see mf2.couple):

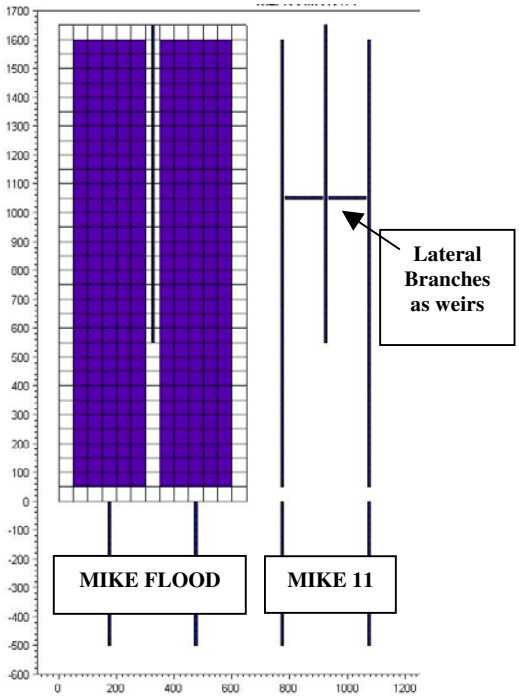


Figure 19 Lateral Link Test 1 Layout (2)

The MIKE 11 test has two branches representing lateral flow aligned equally at the centre of the upstream branch. Comparison of discharges from the downstream branches for the MIKE FLOOD and MIKE 11 tests are presented below:

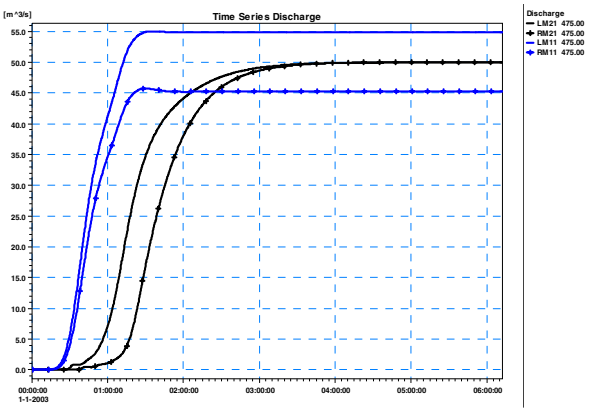


Figure 20 Lateral Link Test 1 Results – Time Series of Discharge (2)

Both the MIKE FLOOD and MIKE 11 simulations preserve mass, with the amount of flow leaving the system exactly the same as the amount entering. However, the MIKE FLOOD and MIKE 11 simulations each give different distributions between the left and right banks. There are several possible reasons for this:

- MIKE FLOOD accounts for the water level gradient in the channel. This increases the accuracy of overbank flow calculations.
- MIKE FLOOD calculates weir flow across each calculation point (20 in total), whereas the MIKE 11 simulation calculates weir flow at one calculation point.
- It is possible that additional losses from 2D effects (such as eddy formations) in MIKE 21 are contributing to the lateral link structure losses. This may create a variation between a MIKE 11 prediction and the MIKE FLOOD prediction.

The findings of this test show that the lateral links are mass preserving and behave as expected. Further, the test highlights the importance of using lateral links in situations where there is a significant water level gradient in the in-bank river channel.

Finally, an AD simulation is added to the test. To do this, add the AD computation to MIKE 11 and MIKE 21, then set the MIKE FLOOD Coupling Type to be “HD and AD”.

The time series plot displays pollutant concentrations entering the upstream boundary and flowing out the two downstream boundaries:

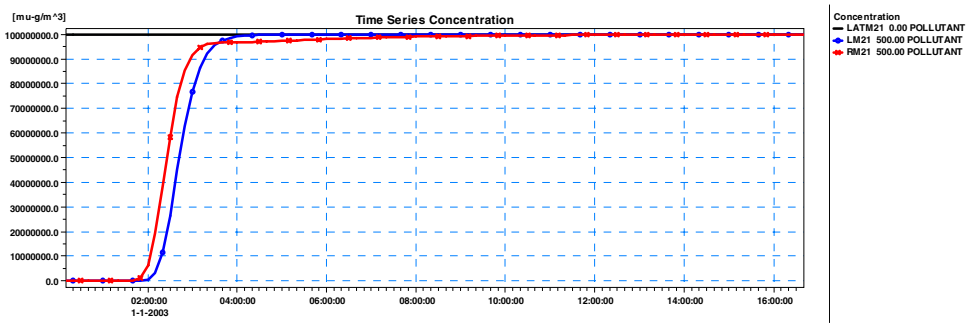


Figure 21 Lateral Link Test 1 Results – Time Series of Concentration

Also, contour plots of concentration in the MIKE 21 domain are shown at two instances:

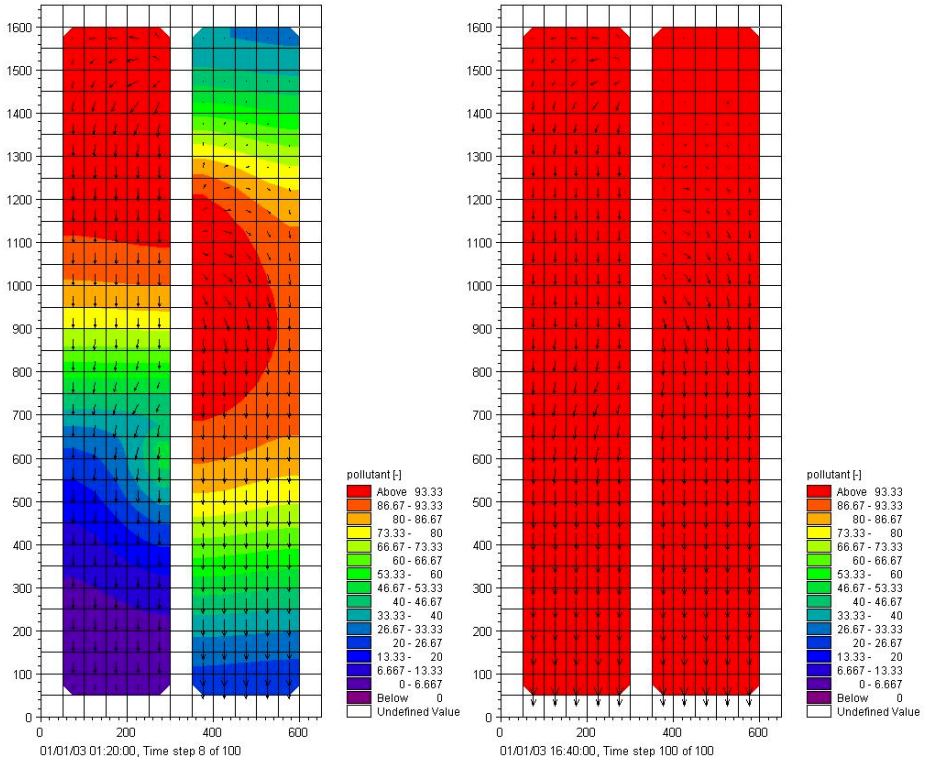


Figure 22 Lateral Link Test 1 Results – Concentration

8.3 Lateral Link 2

This is a test to ensure that the structure equation in the lateral link is consistent with that in a standard MIKE 11 simulation. The first test is a simple MIKE FLOOD model that has a MIKE 11 branch linked to a MIKE 21 basin using a standard link:

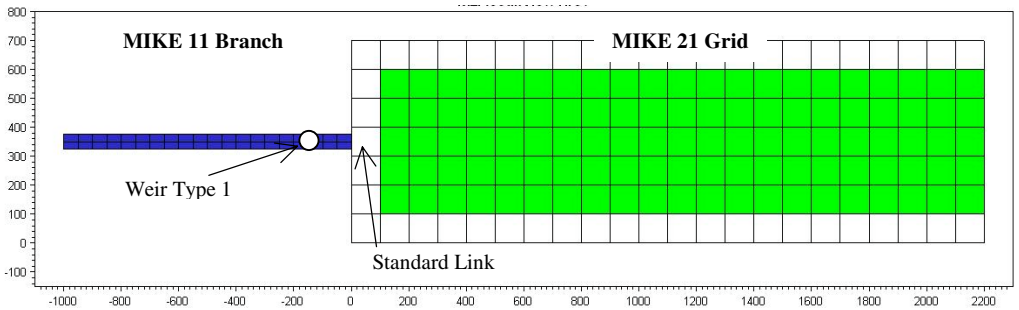


Figure 23 Lateral Link Test 2 – Standard Link Layout

The MIKE 11 branch is 1000 m long with a uniform cross-section of width 500 and bed level 0 m. The MIKE 21 basin is also 500 m wide with a bed level of 0 m, and is 1000 m long. Grid spacing is 100 m. The MIKE 11 branch has a weir located near the link (chainage 850 m). This weir has a height of 2.2 m and is 500 m wide. A weir formula 1 is applied.

The second test aims to replicate the first, except using a lateral link rather than a standard link. The MIKE 11 branch (branch1) is the same as the first test except it is truncated at the weir location (at chainage 800 m) where another branch (latb) is attached. This branch has a length of 500 m, and the left banks of the cross-sections have a bed level of 2.2 m. The lateral link connects this branch to the MIKE 21 basin. A weir formula 1 is applied in the lateral link.

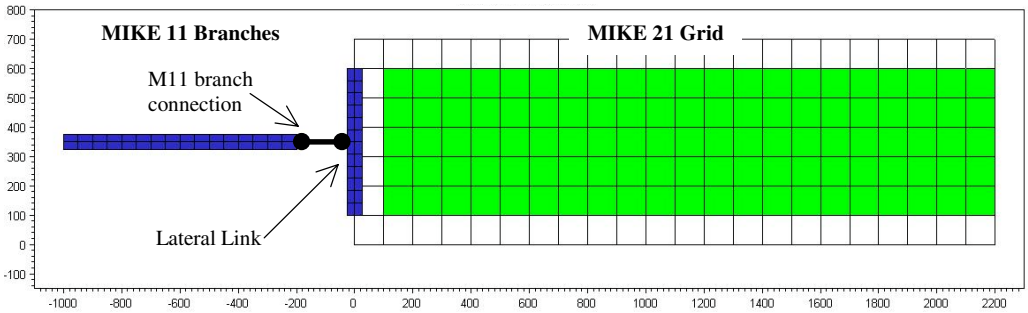


Figure 24 Lateral Link Test 2 – Lateral Link Layout

The initial water level and the downstream water level at the MIKE 21 boundary is 2 m (so water depth is 2 m in the upstream branch and in the MIKE 21 grid). The simulations are performed using a timestep of 30 s (explicit Courant conditions). The upstream flow boundary in MIKE 11 gradually rises from 0 m^3/s to 100 m^3/s and remains steady at this flow rate.

The resulting water level at the upstream end of the MIKE 11 branch and the discharge at the downstream end are presented below:

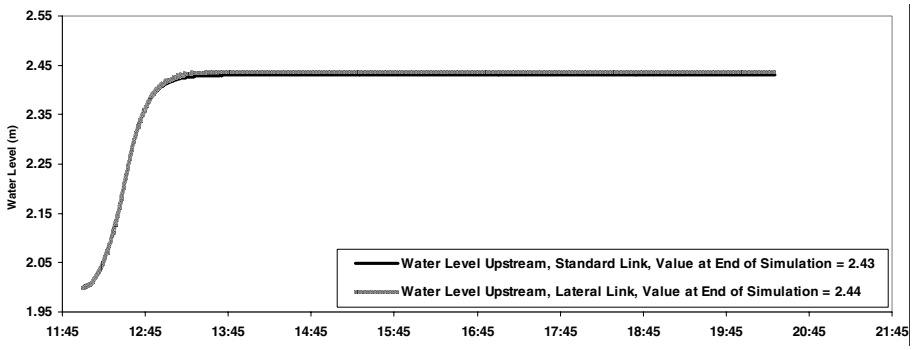


Figure 25 Lateral Link Test 2 Results – Time Series of Water Level

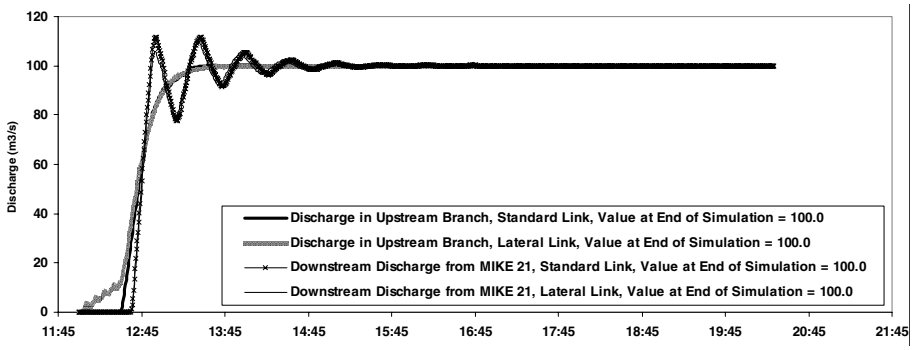


Figure 26 Lateral Link Test 2 Results – Time Series of Discharge

There is a slight variation in water levels as the discharge increases, but the steady state levels are similar for both simulations (2.43 m and 2.44 m). These variations may be due to the missing momentum transfer across the lateral links. Steady state discharge is the same for both simulations (100 m^3/s), indicating that mass is conserved through the links. Notice the oscillations in the discharge at the downstream end of the MIKE 21 basin. This is a result of reflections in the MIKE 21 model, created as the initial wave front produced by the rising discharge enters the MIKE 21 domain.

The water level contours and current vectors in MIKE 21 for each simulation are presented below. Notice that there is a slight variation in flow distributions in the laterally linked case (the variations are shown by the velocity vectors in the link cells).

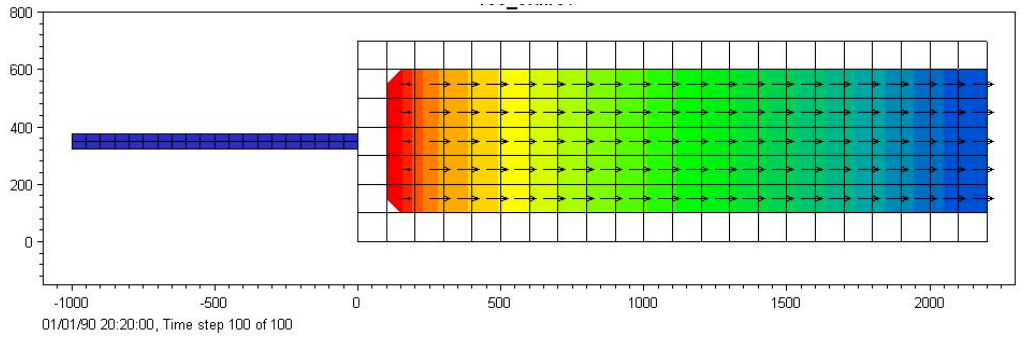


Figure 27 Lateral Link Test 2 Results – Standard Link

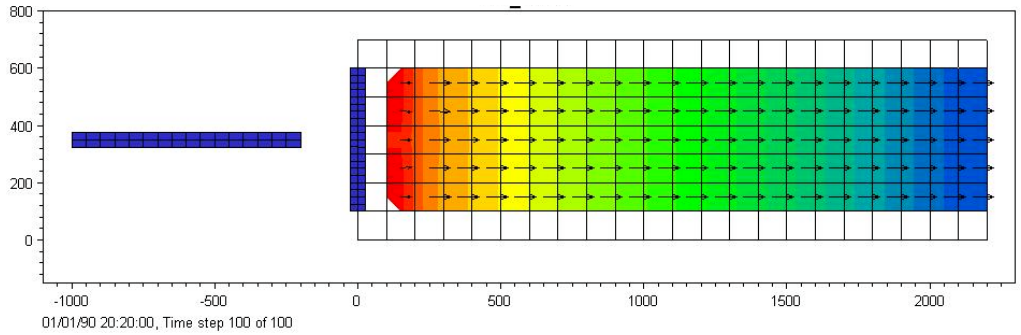


Figure 28 Lateral Link Test 2 Results – Lateral Link

8.4 Flow Direction

This test was initially designed to test links applied in a direction that is not aligned with the MIKE 21 grid. However, it evolved into a demonstration of all the link types available in MIKE FLOOD.

The test consists of a square MIKE 21 basin with a variety of MIKE 11 branches discharging flow into it. The branches are aligned at different angles to the MIKE 21 grid, and consist of standard and lateral links. In the centre of the basin is a lateral link that drains the basin. Using the zero flow links, the bottom right corner has been isolated from the rest of the basin, except for two structure links on each side. The structure links are connected to 3 point MIKE 11 branches with a weir. Some of the link cells in MIKE 21 are completely surrounded by wet cells. Others have land cells, or alternatively zero flow links, inserted behind the link cells.

The MIKE 21 grid size is 10 m and the initial water level is 1 m. A constant discharge of 10 m^3/s is applied to the upstream end of each branch, and the timestep in both MIKE 11 and MIKE 21 is 2 s.

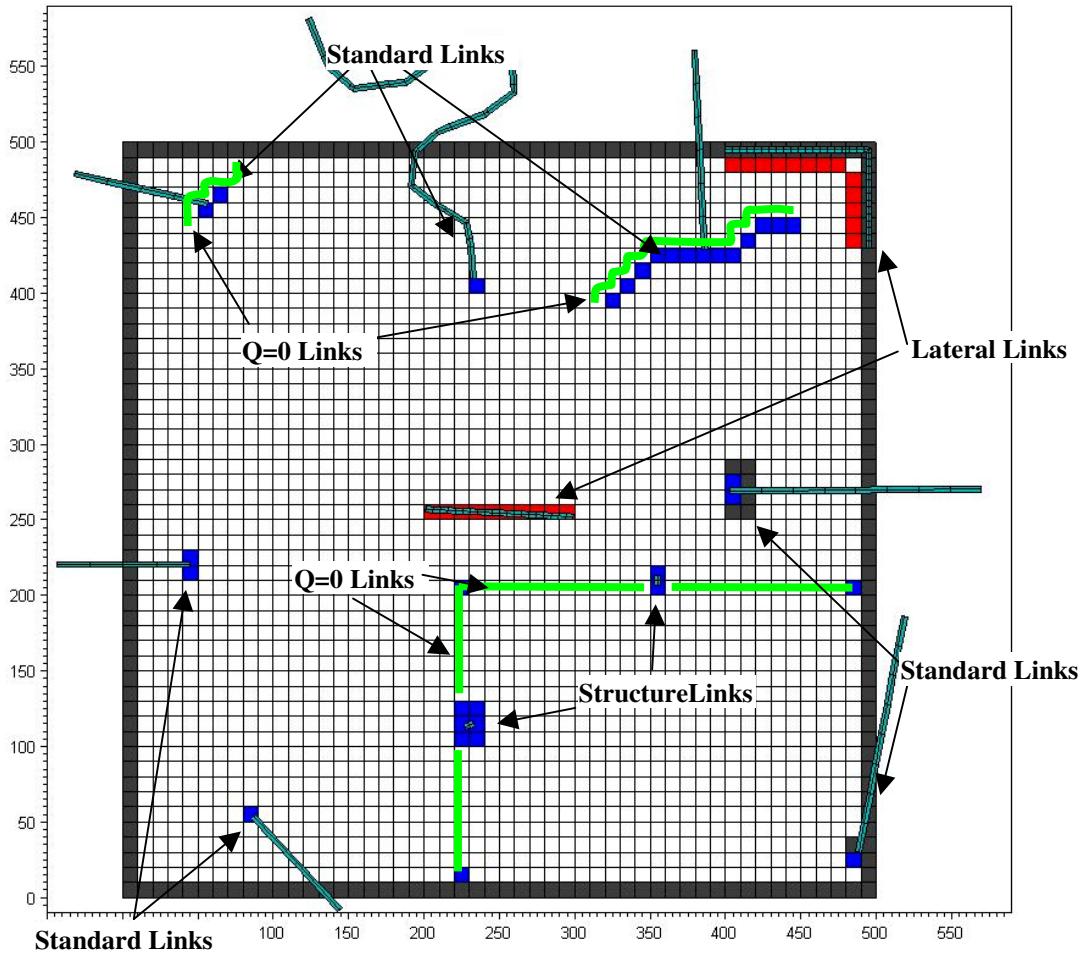


Figure 29 Flow Direction Test Layout

The HD simulation, run to steady state conditions, is presented below:

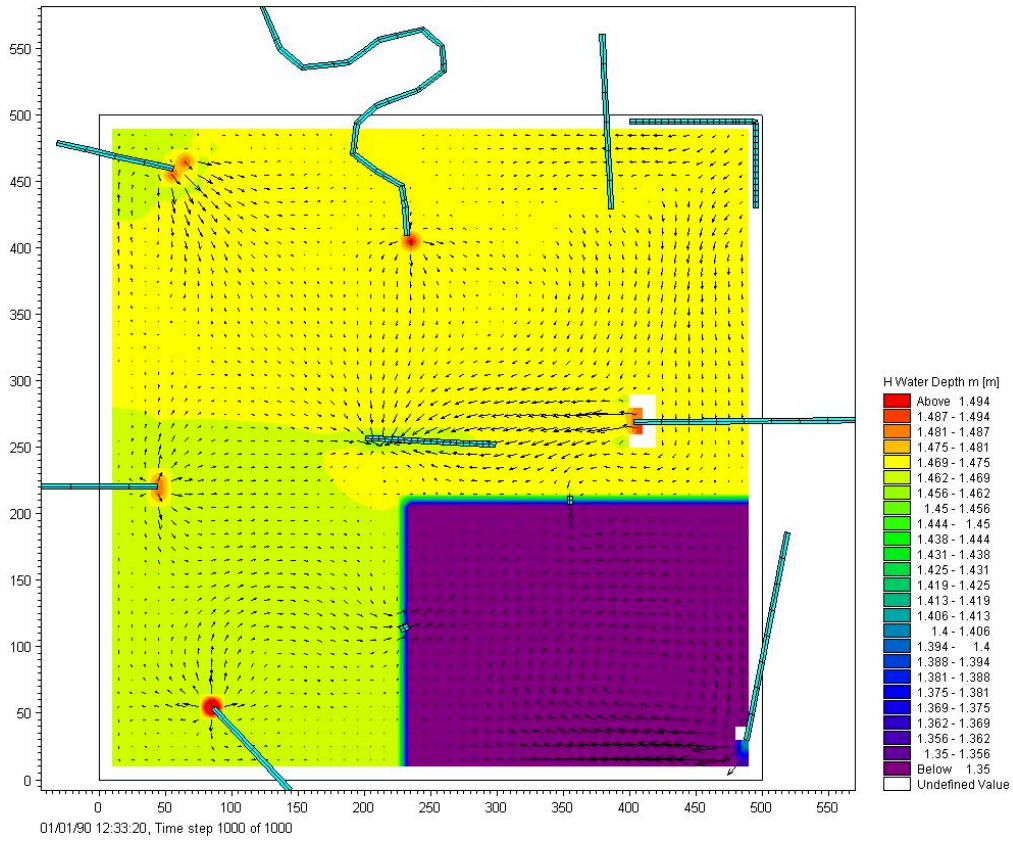


Figure 30 Flow Direction Test Results – Water Depth and Velocity

As shown, the direction of flow discharging from each linkage point is consistent with the branch alignment. The link points that have land or zero flow links behind them show slightly different flow patterns. As a result of the zero flow links, water levels in the bottom right corner are lower than the rest of the model. This is driving flow through the structure links.

An AD simulation was also performed. Initial concentration was set to zero and inflows apply a conservative concentration of 100. The contour plot below shows results:

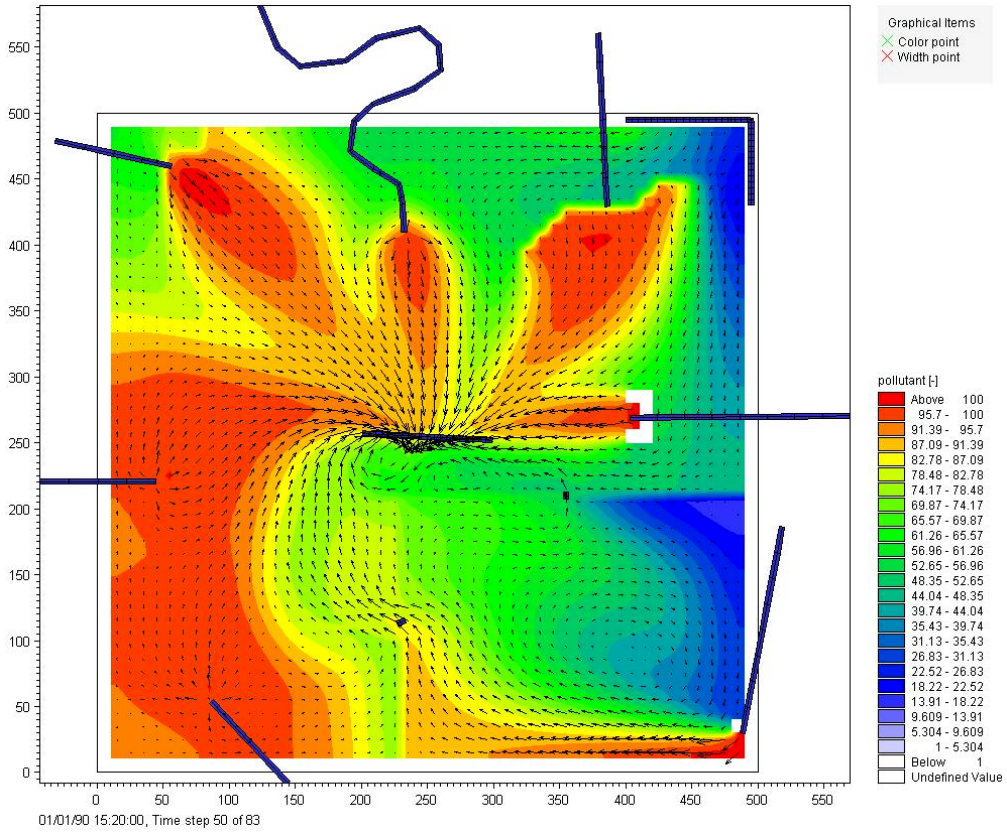


Figure 31 Flow Direction Test Results – Concentration

The flow directions from the links create a slight "whirlpool" pattern. The zero flow links are also zero concentration links – the plot above demonstrates that the zero flow links are a barrier to advection and dispersion.

Finally, a check of mass conservation in the model is made. With 8 separate inflow branches the total flow rate into the system is 80 m^3/s. The resulting discharge through the draining lateral link in the centre of the basin is shown below. At the completion of the simulation, the flow rate shown in MIKE VIEW at the last point in the lateral flow branch is 77 m^3/s. While this may appear to be a mass loss error, in fact it is a minor presentation bug caused by having a lateral link at the last h point in the branch. The discharge presented in MIKE VIEW is at the last q point. As lateral flows are added to the h points, this means that the flow rate of 77 m^3/s does not include an additional 3 m^3/s entering the last h point.

To check this, rerun this simulation with the lateral link connected between chainage 20 to 100 m on the MIKE 11 branch (branch9). The discharge at the last point will then be presented as 80 m^3/s, indicating that mass is preserved.

8.5 Implicit Structure Link Test

Structures are an important feature of any river and floodplain model. Applying structures into a one-dimensional model (MIKE 11) uses established structure flow equations that generally consist of a given entrance loss, structure loss and exit loss. In a two-dimensional model, entrance and exit losses can be represented to some extent by turbulence and eddy viscosity losses that occur upstream and downstream of the structure. These losses depend upon grid size and eddy viscosity values in MIKE 21.

Difficulties arise when using MIKE FLOOD because the entrance and exit losses can be represented both in MIKE 21 and MIKE 11. This can create an overestimation of structure losses, which can result in a larger than expected head loss across a structure. To account for this the entrance and exit losses in the MIKE 11 structure equations should be reduced. The question is how much these values should be adjusted, and the answer often depends upon choice of MIKE 21 grid size, eddy viscosity parameter and what type of structure is being applied.

This test is designed to investigate the representation of structure losses in MIKE 21, and how various parameters can effect these losses. While these tests won't answer all questions relating to this subject, it highlights potential problems that may be encountered when using MIKE FLOOD.

Note: At present, this test is still being developed. Please check the web site (www.dhisoftware.com) for latest updates.

8.6 Floodplain Flow

This is another test of the lateral links. It compares model performance over a broad floodplain application. This is a simplified representation of a typical lateral link application – floodplain in MIKE 21, river channel in MIKE 11, and flow between them in MIKE FLOOD.

The test consists of four separate setups:

- MIKE FLOOD –river channel modelled in MIKE 11, floodplains in MIKE 21, connected with MIKE FLOOD lateral links (“mf.couple”)
- MIKE 11 - single branch for main channel and floodplains (“mf.couple”)
- MIKE 11 – separate main channel and floodplain branches, interconnected by link channels (“mf.couple”)
- MIKE 21 – both river channel and floodplains modelled in MIKE 21 (“m21a.M21”)

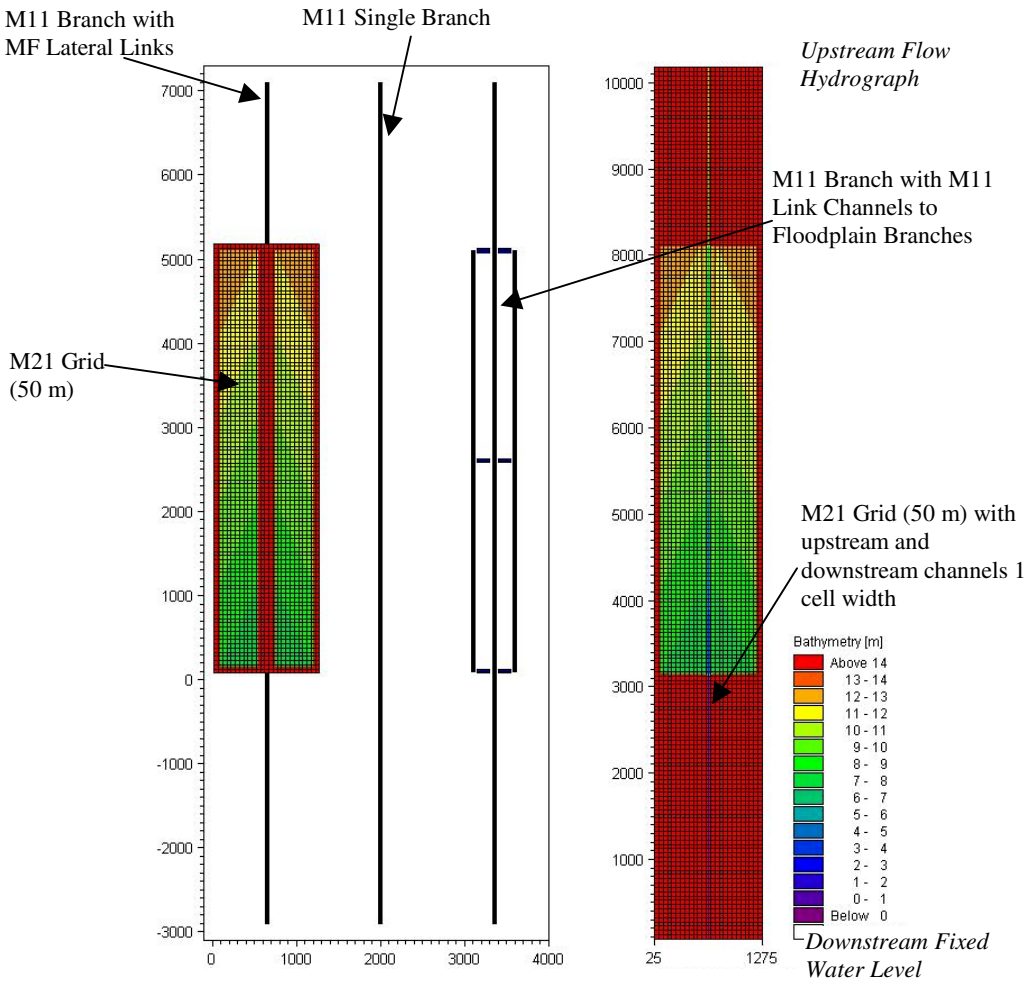


Figure 32 Floodplain Flow Test Layout

Each test represents the same geometry, consisting of a 50 m wide, 5 m deep channel. On each side of the channel is a 50 m wide levee. Beyond the levees the floodplains are initially 1 m below the levees, and rise laterally by 1 m over a distance of 250 m. A typical cross-section is shown:

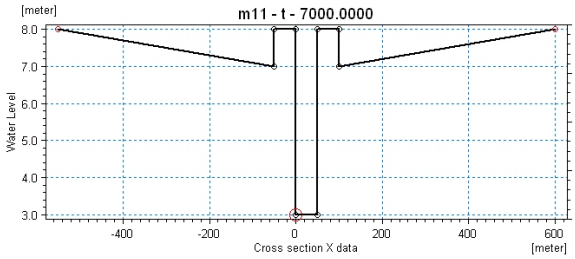


Figure 33 Floodplain Flow Test – Typical Cross-section

The total length is 10000 m. The river has a uniform slope of 1:1000 – the bed of the main river channel upstream is 10 m, and the bed downstream is 0 m.

To each of these setups, an upstream flow hydrograph is applied, which has a peak discharge of 2000 m^3/s. A downstream water depth of 4 m is maintained.

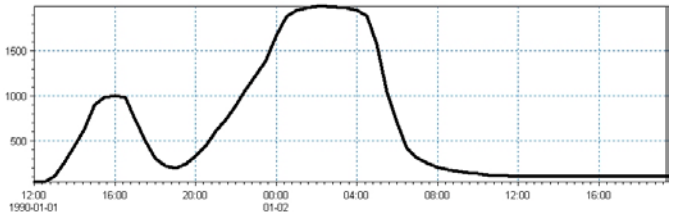


Figure 34 Floodplain Flow Test – Upstream Hydrograph

The water level at the upstream end of each of the four models is presented:

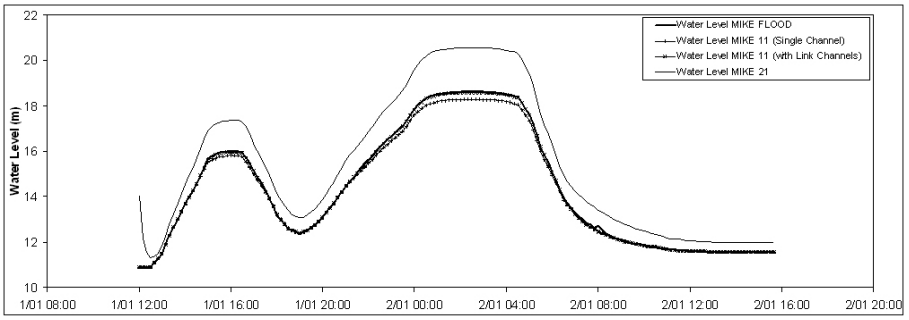


Figure 35 Floodplain Flow Test Results – Upstream Water Level

Further, the discharge at the downstream ends of each model is presented with the upstream hydrograph:

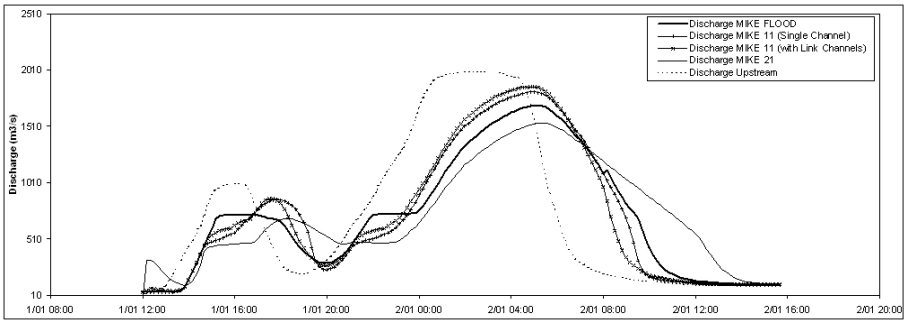


Figure 36 Floodplain Flow Test Results – Downstream Discharge

For each test case the upstream water levels are reasonably consistent with the other. However, the MIKE 21 simulation predicts a higher water level, suggesting more losses along the length of the model. The downstream discharges are also reasonably consistent, although again the MIKE 21 simulation (and to a lesser extent the MIKE FLOOD simulation) have a reduced, more dampened discharge peak. This again suggests more losses in the model.

A possible reason for this variation in model predictions between MIKE 11 and MIKE 21 could be due to wetting and drying in MIKE 21.

8.7 Floodplain Demonstration

This example is available as a demonstration model to illustrate a real application of MIKE FLOOD. The application consists of a flood simulation through a river system. The area of interest is at a confluence with a tributary, where a road embankment has been proposed. Culverts under the road are located on each side of the river.

The river system is represented in MIKE 11. A MIKE 21 grid is inserted into the broader MIKE 21 network to represent floodplain flow, as shown in Figure 37:

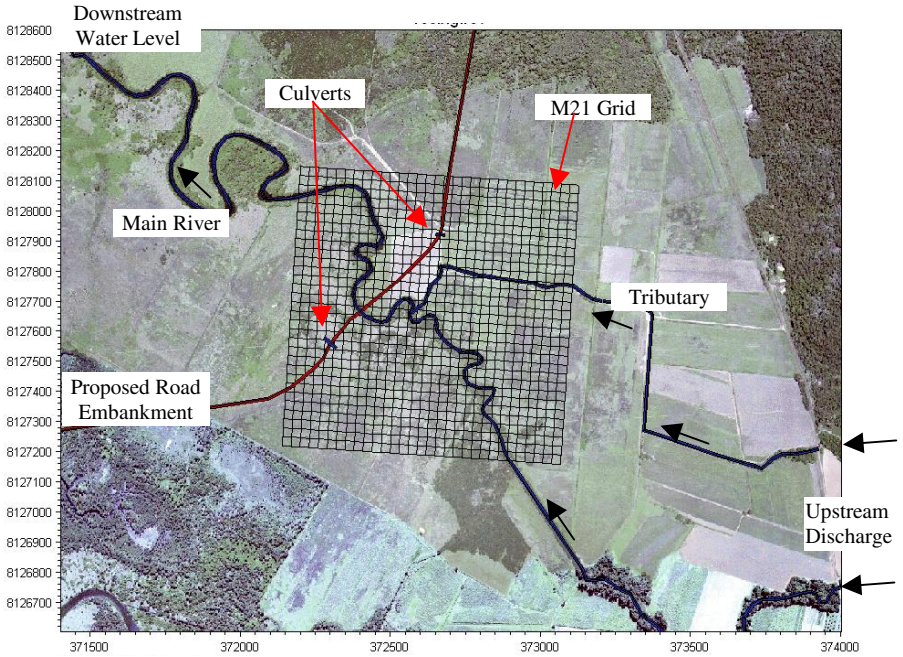


Figure 37 Floodplain Demonstration Layout

A 5 s timestep is used in the simulation and the MIKE 21 grid size is 30 m. The model has been developed with the following MIKE FLOOD links:

- **lateral links** between the main river channel and floodplain and the tributary and floodplain
- **zero flow links** along the centre line of the river channel, to ensure that water flows from one side of the floodplain to the other via the main channel
- similarly, **zero flow links** along the centre line of the tributary
- **zero flow links** defining the road embankment (assuming that the road does not overtop)
- implicit **structure links** for flow through the culverts

A diagram illustrating the locations of the links is shown:

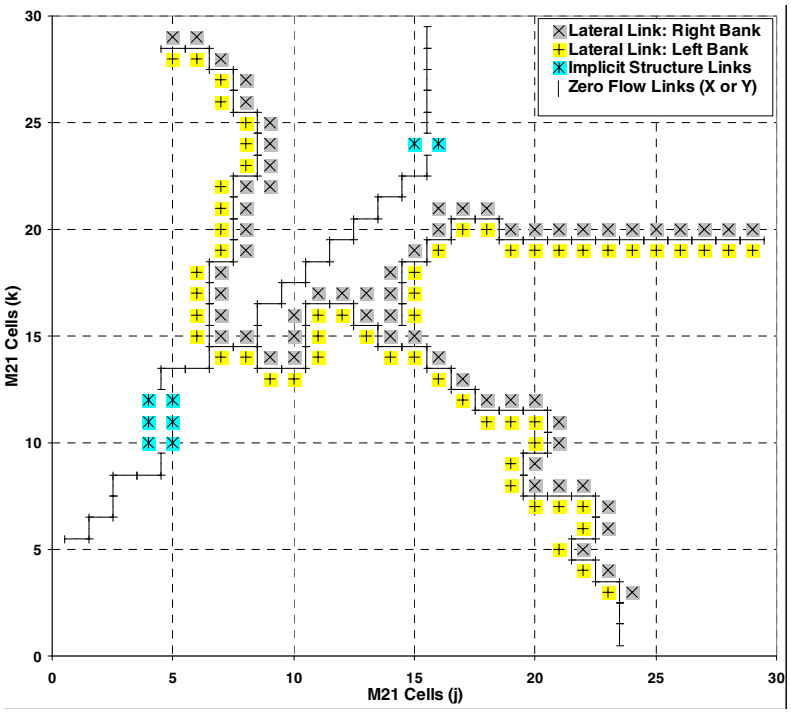


Figure 38 Floodplain Demonstration, Diagram of MIKE FLOOD Links

The upstream discharge hydrographs for the river and tributary and the downstream water level boundary condition (which is tidal), are shown below:

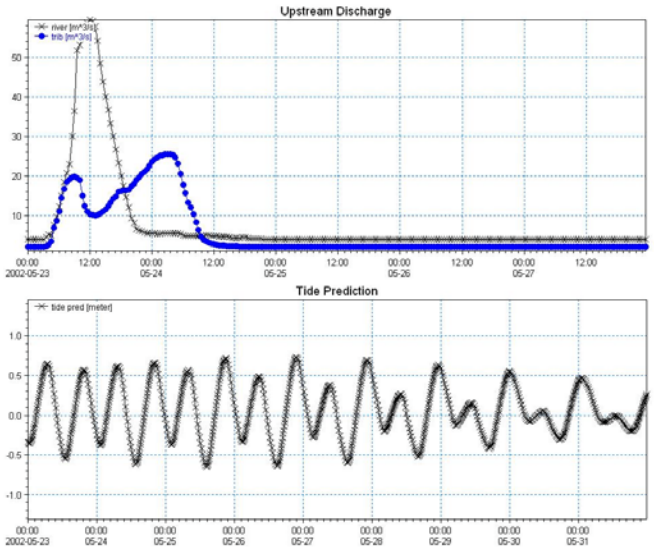


Figure 39 Floodplain Demonstration Boundary Conditions

Model results showing water surface contours and velocity vectors near the peak of the flood event are presented in Figure 40. The time series plots in Figure 41 show water levels

immediately upstream and downstream of the road embankment, and water level difference across the road embankment. Also shown is discharge through the main river channel and through each culvert.

The model results show that for this particular flood event there is a peak 0.36 m head drop across the road embankment. However, the peak head drop at the peak of the flood is 0.16 m. Peak discharge through the main river channel is 44.2 m^3/s, which is much higher than the culvert flows of (1.7 m^3/s and 3.8 m^3/s).

If this model was intended to investigate the hydraulic impacts of the road embankment, a model of the existing situation (no road) could also be performed. Comparing model results with and without the road embankment could give an indication of the likely impacts. Also, the performance of the culverts could be assessed (maybe more are needed?).

Note that this is a demonstration model – not a real example. Other modelling considerations that could be of relevance in this example include:

- The MIKE 21 grid does not cover the entire floodplain width.
- The proposed road crosses over the main channel. Any hydraulic effects (bridge structure or pier losses) created by this situation are ignored.
- The roughness parameter on the floodplain has been set to a constant value of M=20. The roughness may actually be varying spatially, particularly if there are a range of land use patterns.
- The upstream and downstream MIKE 11 branches only represent the main channel. They do not include the floodplains.

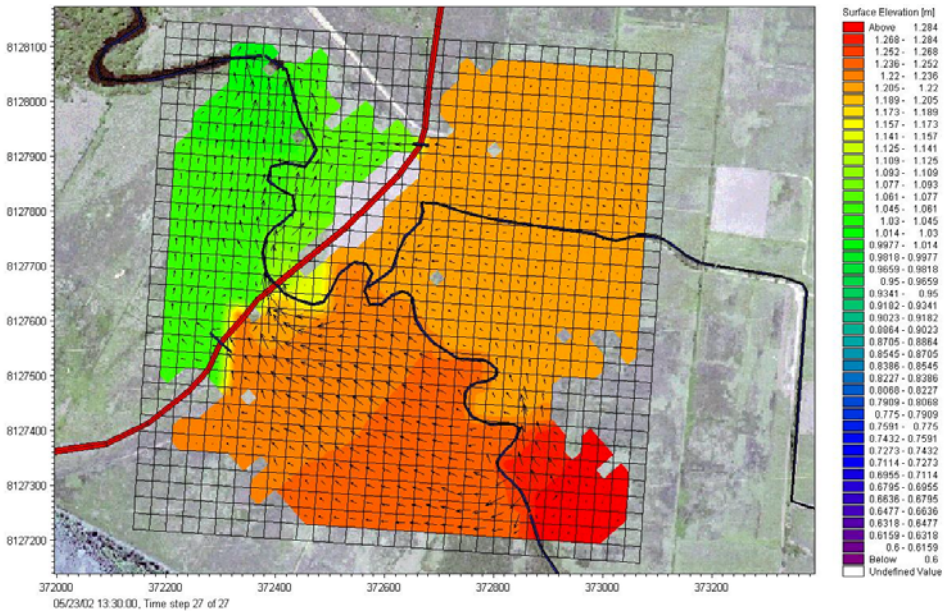


Figure 40 Floodplain Demonstration, Water Surface and Velocities near peak of flood

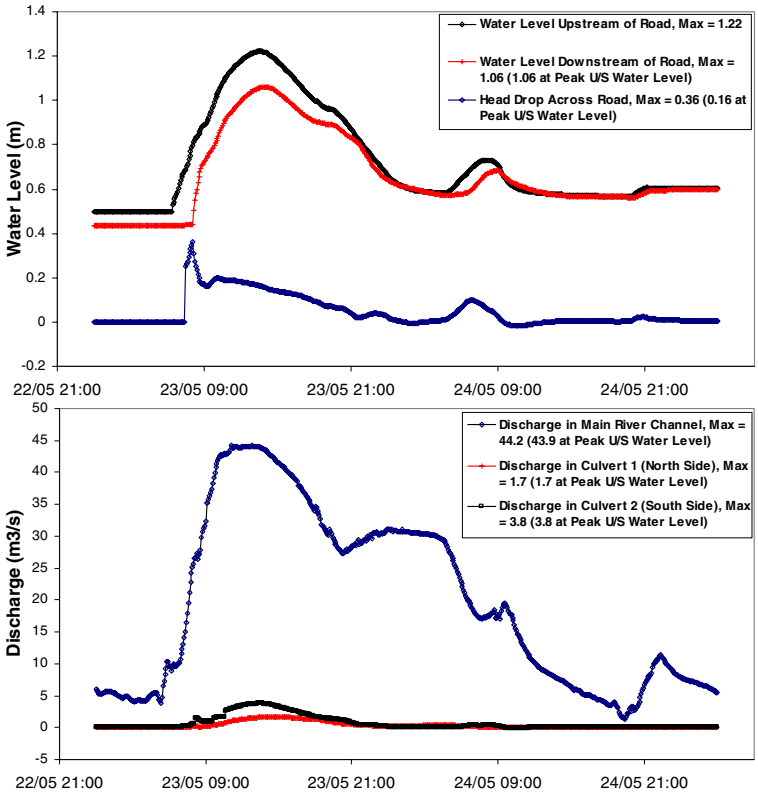


Figure 41 Floodplain Demonstration Results – Water Levels and Flows at Road Embankment